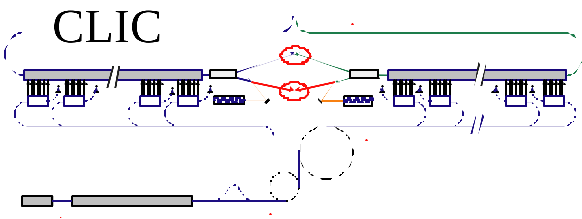
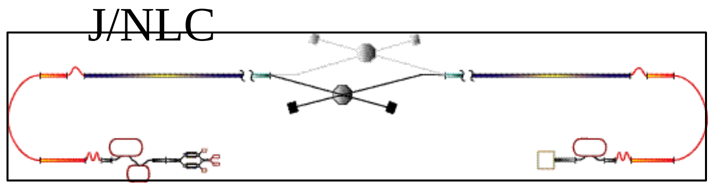
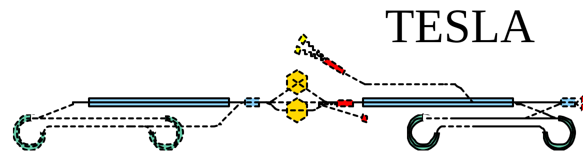
Linear Collider Beam Instrumentation

Monday, April 8, 2002

Marc Ross







Does Accelerator-Based Particle Physics Have a Future?

- We can't just leave the design of frontier accelerators to the specialists. Inventing clever new ideas requires the same talents that it takes to do experimental physics.

Maury Tigner
Physics Today – January 2001

Assuming this to be basically correct …

How can we make it work?

Chris Quigg – Snowmass 2001 closing plenary:

▷ Thanks to the work of many people, the moment is upon us to probe, shape, and judge the idea of a linear collider as a possible next big step for particle physics.

Evaluating a linear collider and working to define a scientifically rich, technically sound, fiscally responsible plan is a homework problem for the entire community.

Everyone must come to an informed judgment.

At Snowmass 2001, a widespread feeling has emerged that the world community should move urgently to construct a TeV-scale linear collider as an international project.

These are ambitious machines and significant challenges remain: we must be certain of the osts and we must take the measure of technical risks. A phase change is needed to complete the design and development promptly.

In the United States, another phase change is needed *soon* in the commitment of experimental physicists to the linear collider program.

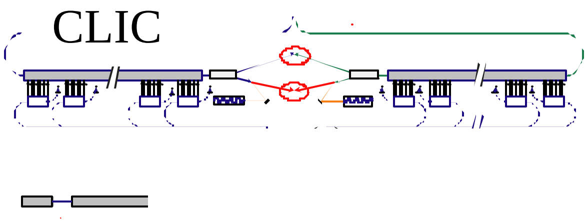
A few people have done valuable work, but outside the US, *many more people* have done much more comprehensive work.

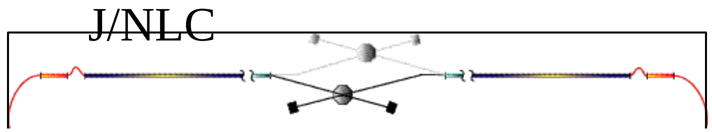
US participation in a linear collider will not be decisive without the engagement of a large and energetic cadre of superb experimenters to hone the physics case, participate in parameter choices, and work side-by-side with the machine builders. *If you wait, it will not happen!*

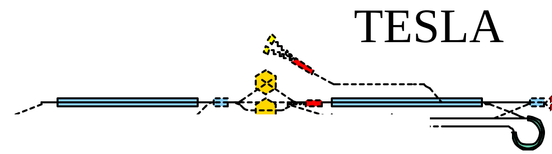
It is also time for closer cooperation among physicists in different regions on linear collider issues: to coordinate R&D, to develop a unified physics document, and to make the scientific case to the governments of the world—perhaps an International Linear Collider Users Group?

(mine)

(Chris Quigg)



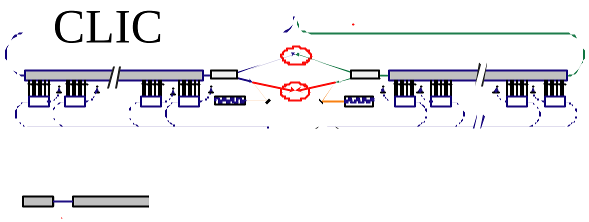


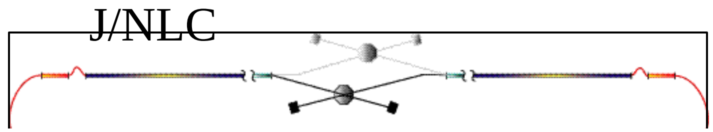


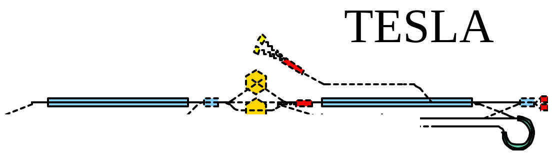
LC time scale

- CDR ~ 2004
- Start constructing components ~ 2005

- RD goal is to
  - reduce cost,
  - maximize use of clever ideas,
  - demonstrate feasibility,



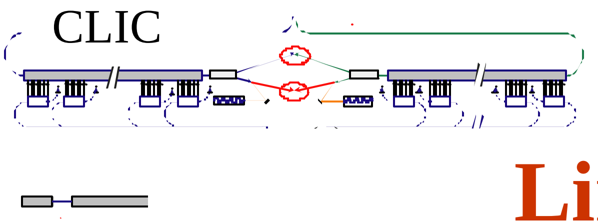


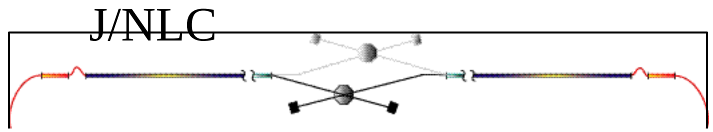


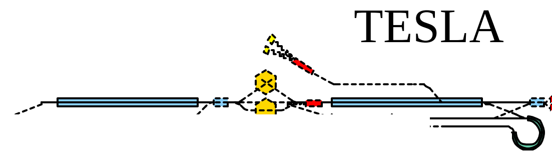
This talk:

- Only suggests the nature of collaborative efforts (phase change?)
  - Not a set of requisitions carved up in detail
- Does not detail ‘plug and play’ activities
- Is not a ‘status’ update
  - Does not detail who is up to what
- Illustrates technologies and hints at opportunities
- is NLC/TESLA/CLIC neutral

- SLC Experience:
- Substantial contributions from collaborators
  - especially software



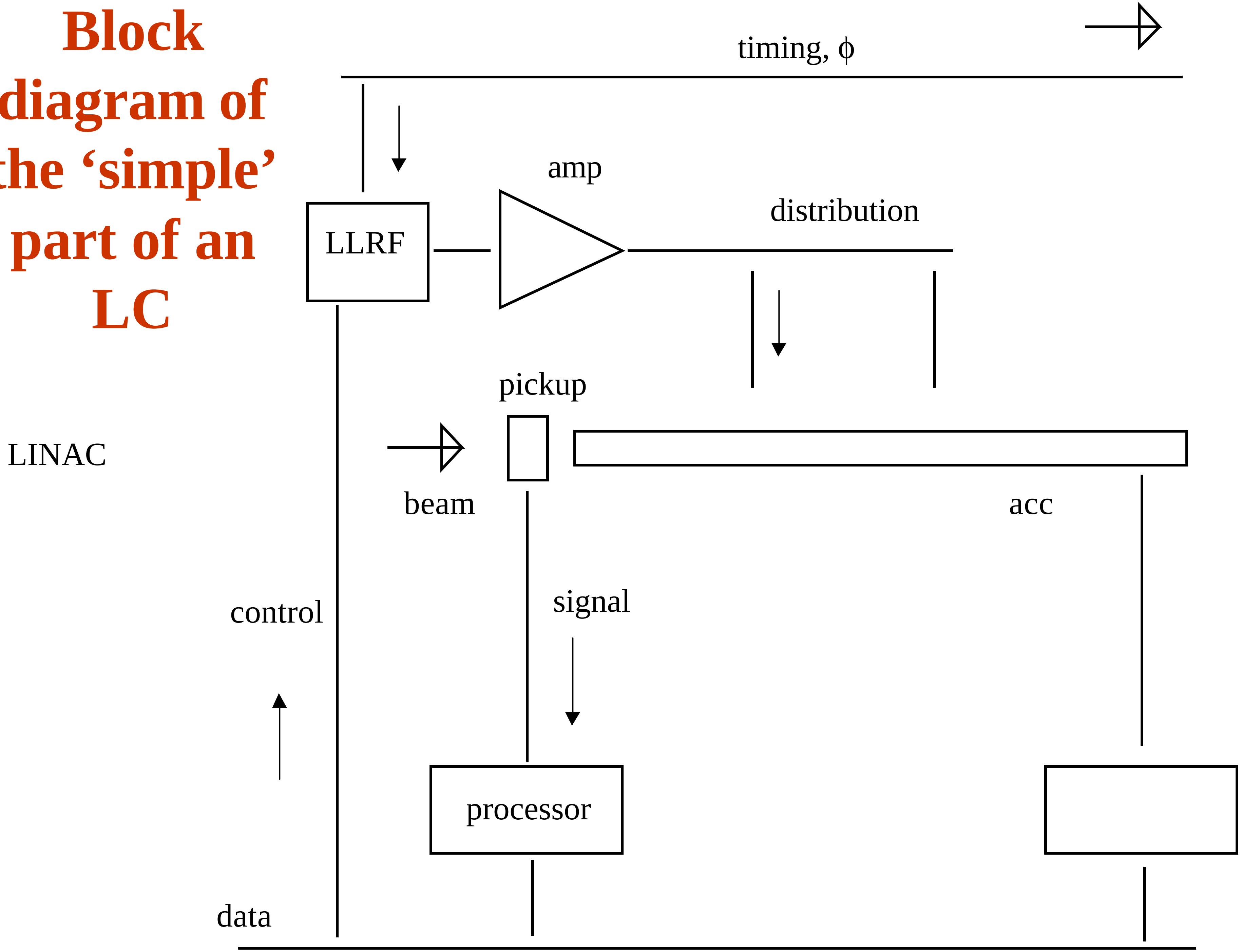


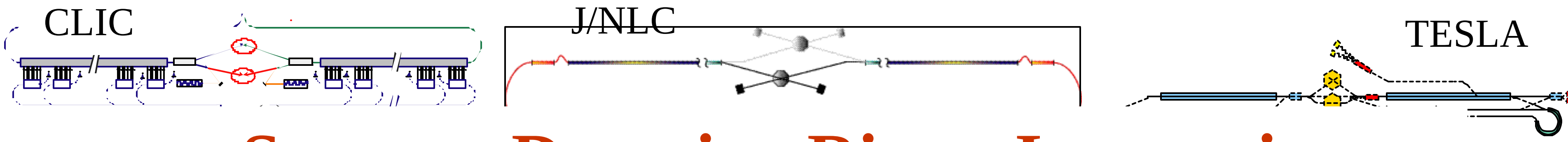


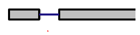
Limiting LC technology:

- (not including physics of beams)
- gradient & RF power & associated diagnostics
- Low power µwave circuitry
- Lasers
- Positioning/alignment/vibration stabilization
- mm wave & FIR diagnostics
- Data flow – control system
- Radiation effects
- Vacuum
- Feedback
- Engineering – fabrication, packaging, testing

Block diagram of the 'simple' part of an LC

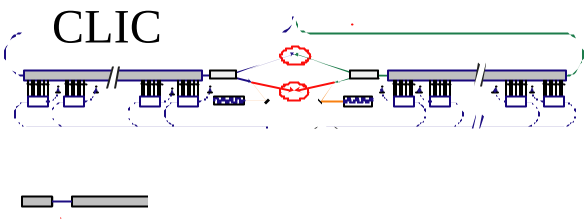


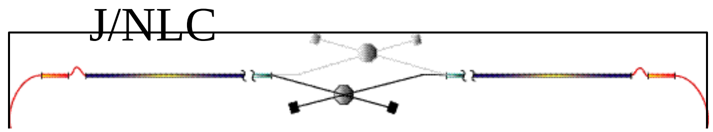


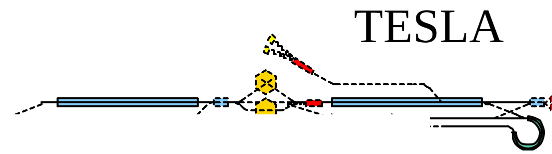


Sources, Damping Rings, Interaction region

- (Broader) range of issues than linac
  - Materials science
    - photocathode
    - positron system
    - radiation effects
  - Surface science
    - secondary emission
    - UUHV (1e-12 Torr) – (e.g. Polarized e- RF gun)
  - Synchrotron radiation

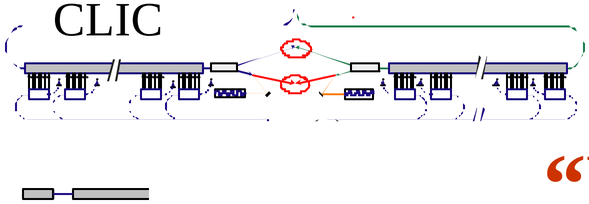


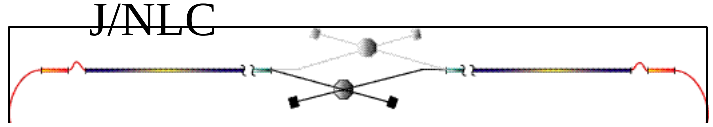


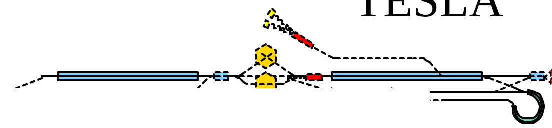


R&D Challenges

1. Precision microwave
2. IR final doublet girder (~ internal to detector)
3. Beam size from optical transition/diffraction radiation
4. Bunch length
5. Storage ring instabilities – electron cloud
   – surface physics
6. Radiation modeling
7. Permanent Magnets
8. RF breakdown
9. Control system



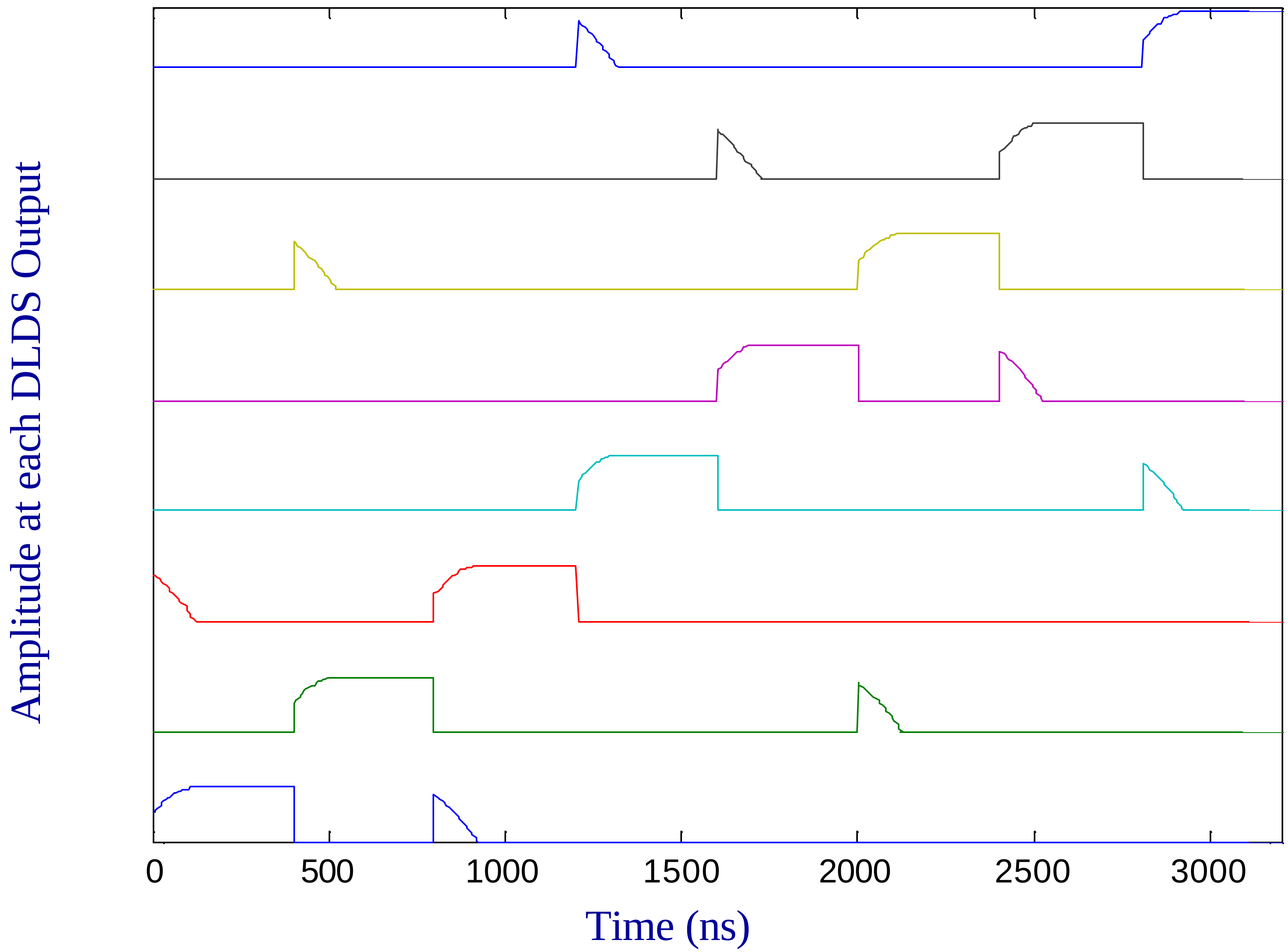




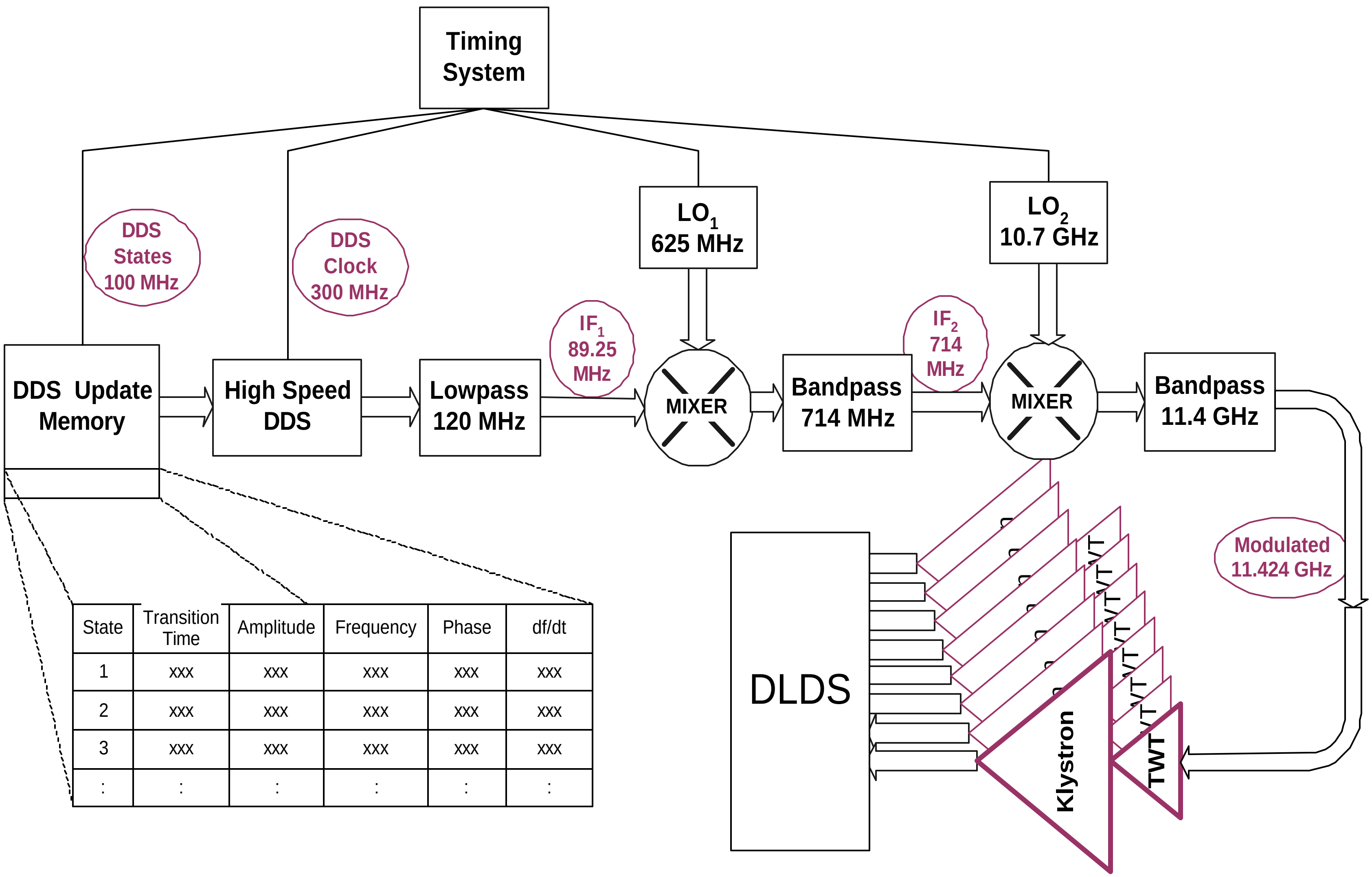
“Precision” microwave

- High power controls and monitoring + position monitors + beam phase monitors
  - Cavity tuning at TESLA; lorentz force compensation + coupling control
- programmed phase control
- external measurements of phase and amplitude
  - TESLA Test Facility uses a sequence of stabilization loops and associated processors
  - NLC/SLC uses thermal stabilized power and phase measurements

DLDS Waveforms with Beam Loading Compensation



Linac LLRF Drive

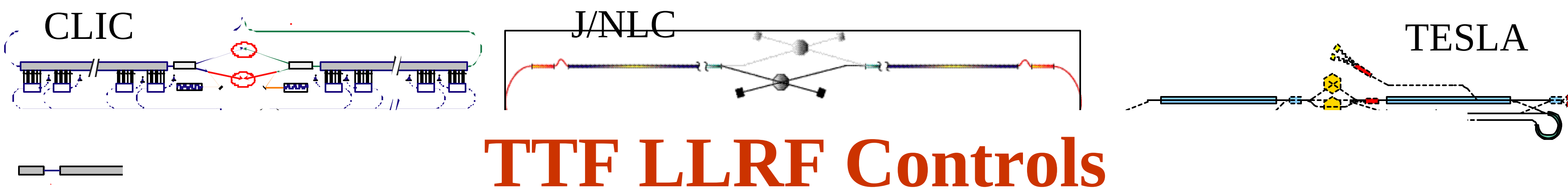


State	Transition Time	Amplitude	Frequency	Phase	df/dt
1	xxx	xxx	xxx	xxx	xxx
2	xxx	xxx	xxx	xxx	xxx
3	xxx	xxx	xxx	xxx	xxx
:	:	:	:	:	:

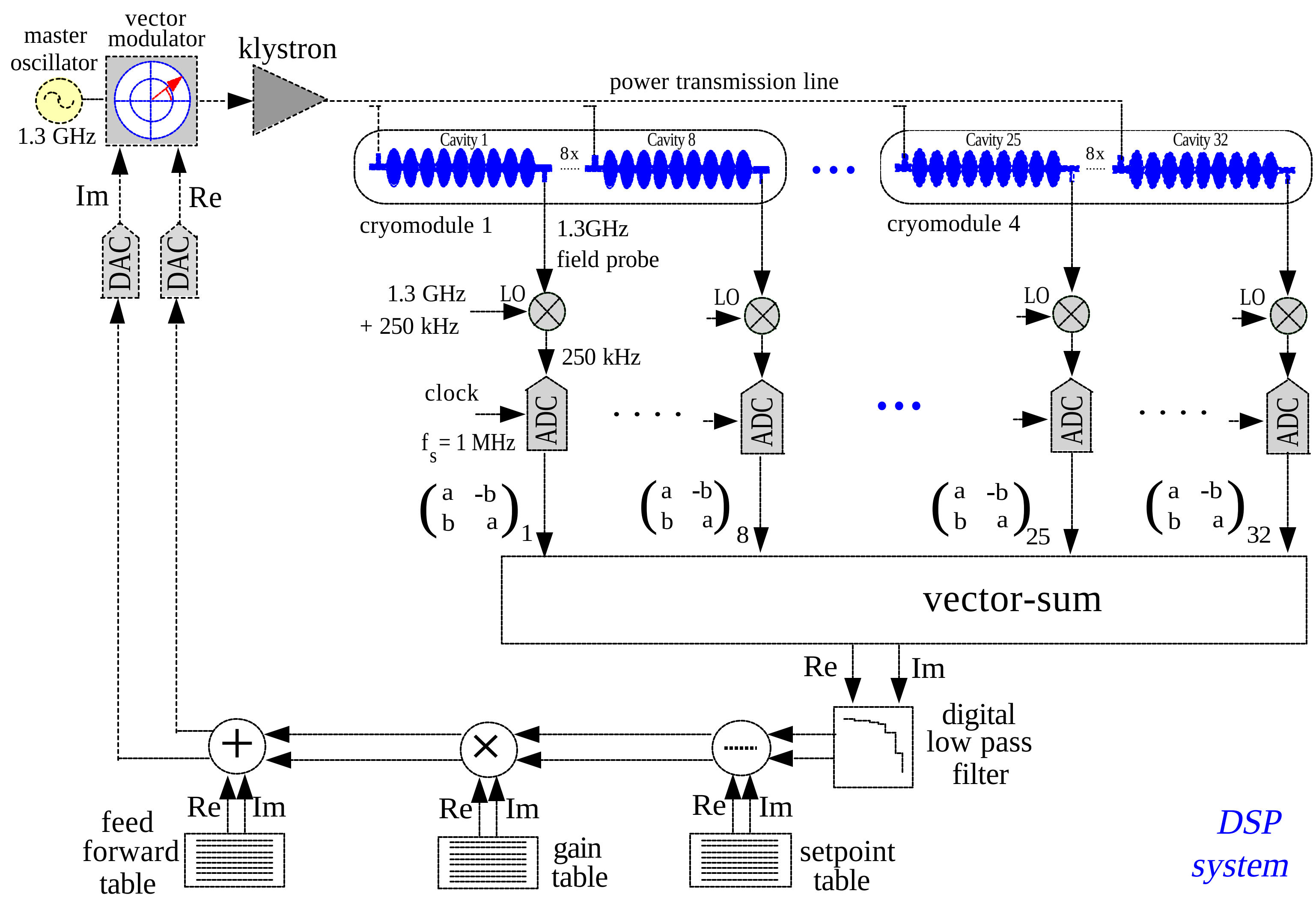
NLC Linac LLRF

Measurement Requirements

Parameter	Value	Details
Bandwidth	> 100 MHz	at -3 dB
Rise time	< 5ns	10% to 90%
Phase resolution	1 degree	At 11.424 GHz
Dynamic Range	> 20 dB	
Amplitude Resolution	10^{-3} of full scale	
Beam phase wrt RF	1 degree	At 11.424 GHz
Beam signal / RF	-40 dB	(!)
Reflected power detector max input	< 100 mW	Peak
Reflected power detector rise time	< 10 ns	



TTF LLRF Controls

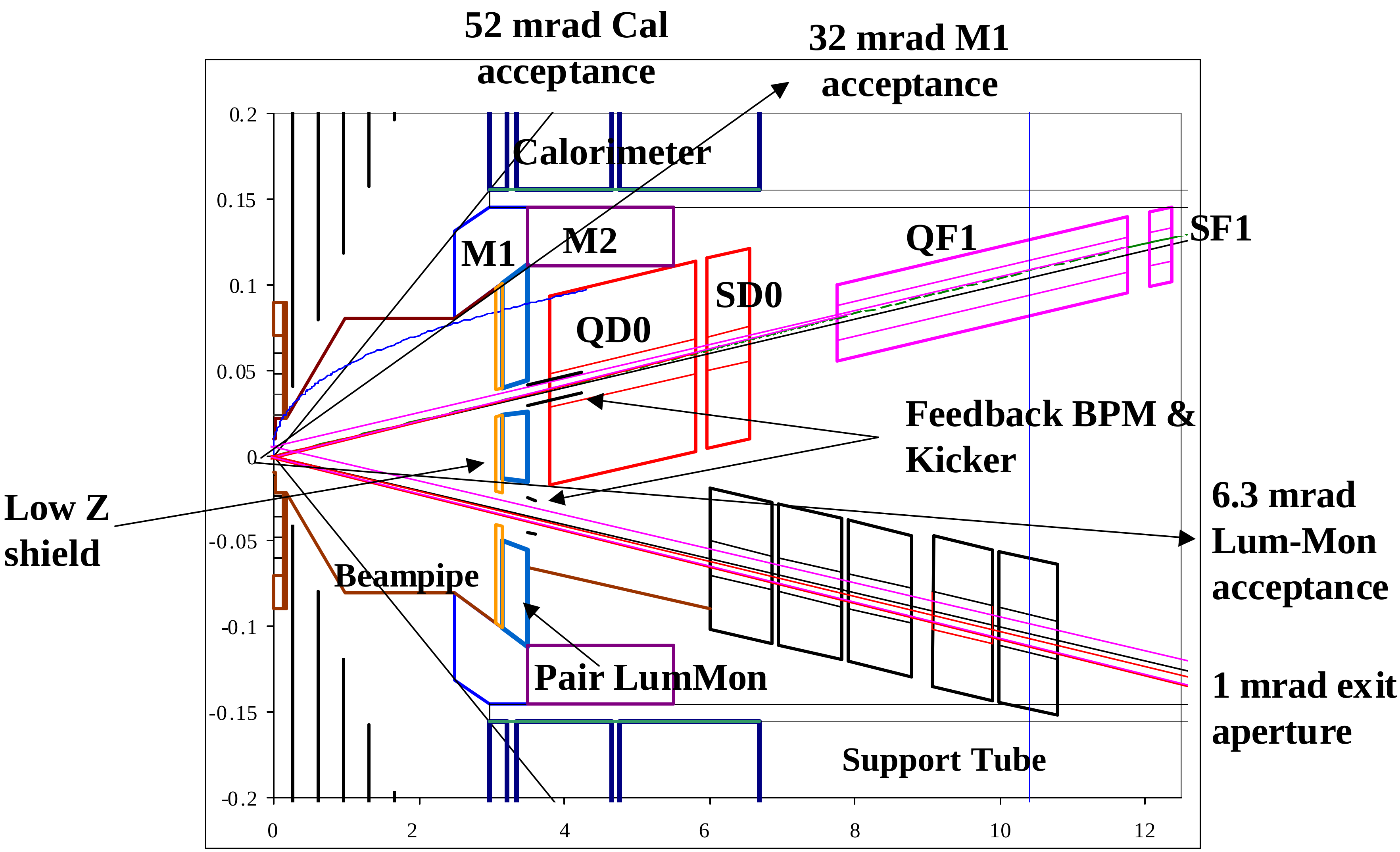


S. Simrock

Final Doublet support girder

- Internal to detector
- Compact Superconducting Quads are the superior technology because of their flexibilty and are the most likely candidate for the final doublet
- R&D in SC Quads is still in the conceptual state
- SLAC team working with PM

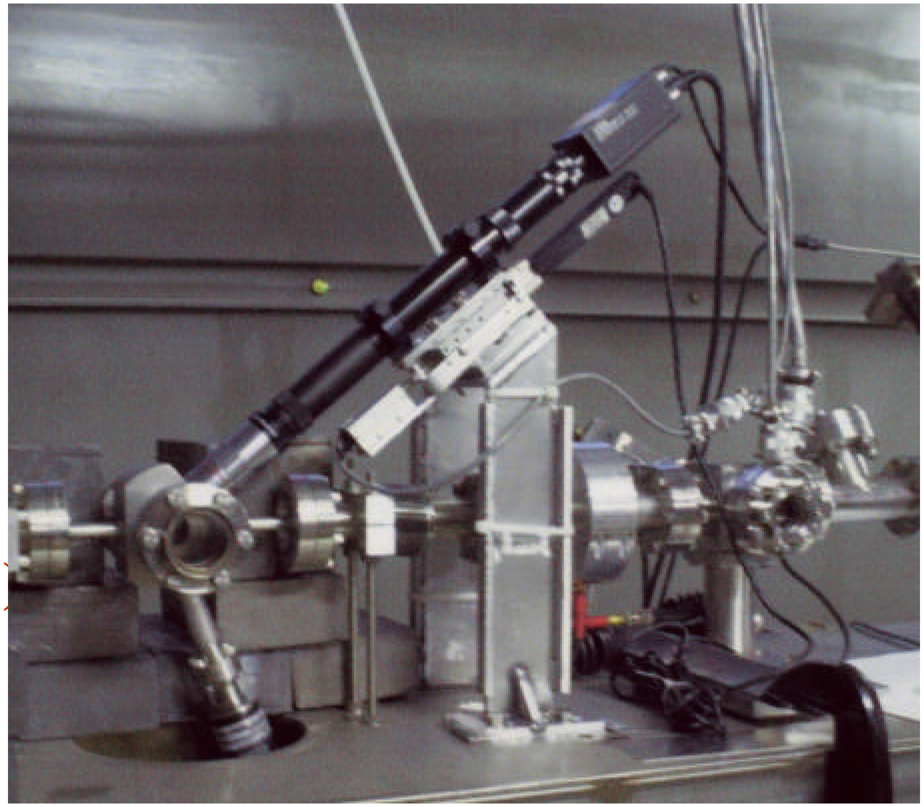
LCD-L2 (3T) with 3.8m L* Optics



Development of a transition radiation profile monitor -OTR

- some controversy over minimum resolvable beam image
  - achieved 7µm (12/00) well beyond purported limit – *OTR provides light at very large angles → high resolution*
  - *not like synchrotron light*
  - smallest OTR spot imaged to date
- theoretical limit: ~ λ

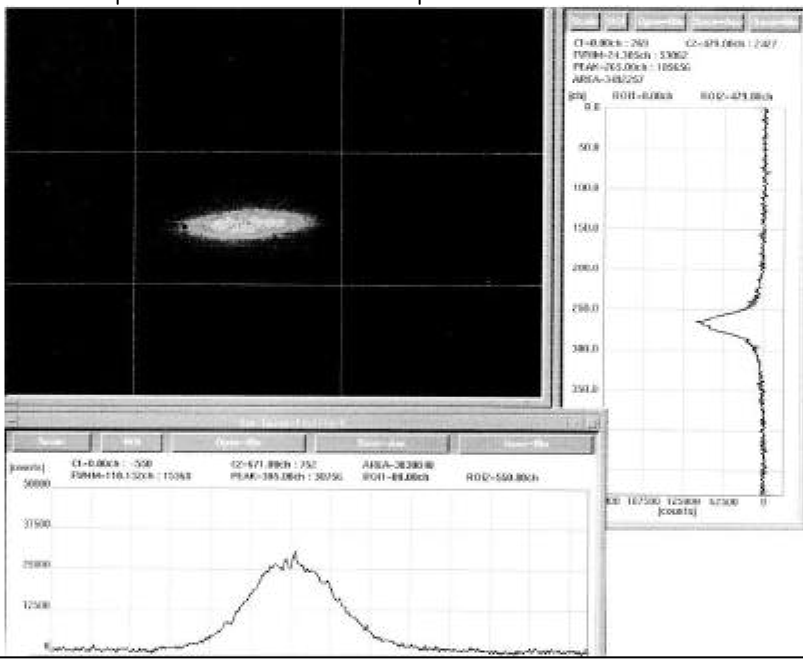
- Parameters for ATF OTR (built at SLAC)
  - resolution – 2µm
  - field of view – 300 x 200 µm (or ~2x)
  - depth of field – 8 µm vertical displacement
  - OK light for normal camera – 5e9 ppb
  - Industrial microscope objective
  - 35 mm working distance
  - various target materials



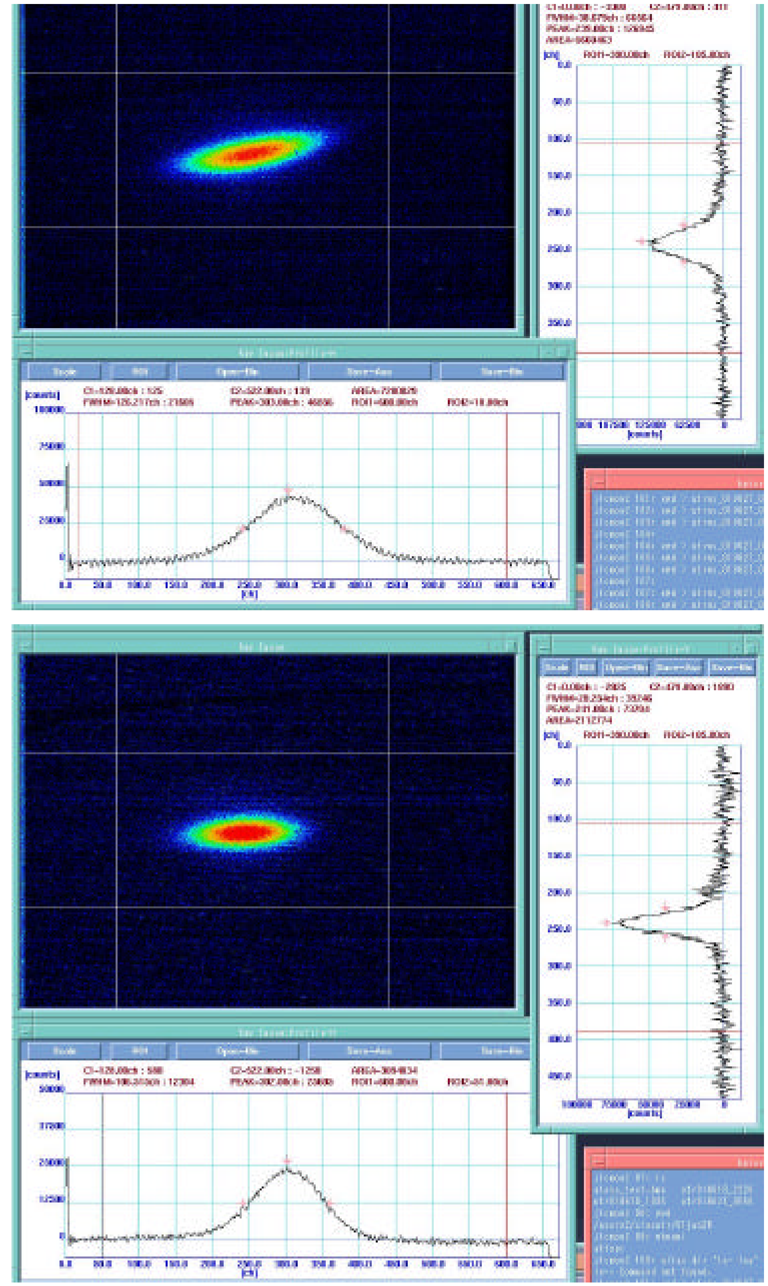
SLAC–built very high resolution OTR

← 0.5mm →

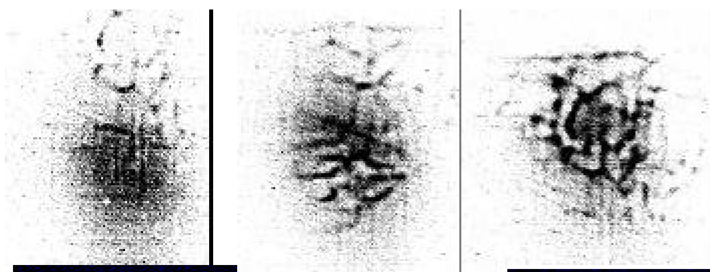
10 µm σ_y



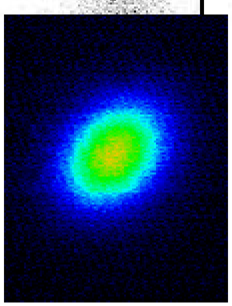
OTR images & target damage



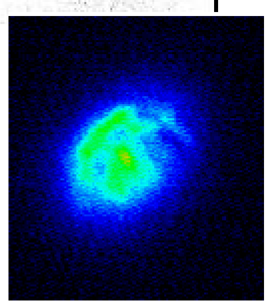
successive images illustrating damage:

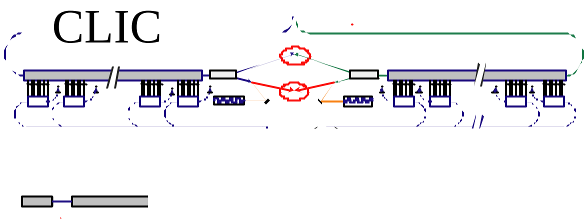


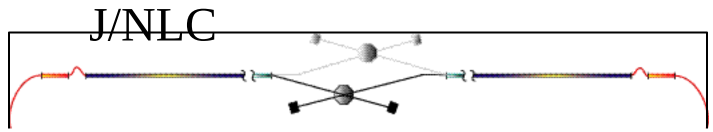
Cu
7e9
20x12µm

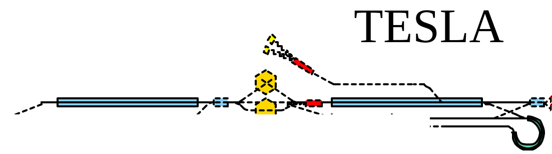


Be 5e10
10x13µm







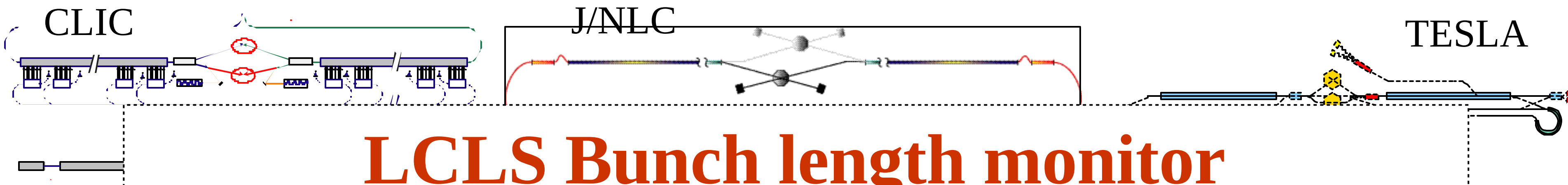


Bunch length

- Streak cameras
  - resolution limited to ~ 1mm
  - space charge, calibration
- Coherent radiation
  - stronger signal with shorter beams
  - asymmetry difficult (use power spectrum – phase info lost)
- Deflecting RF structures
  - promising →
- Broadband microwave emission
  - cheap, relative – a given

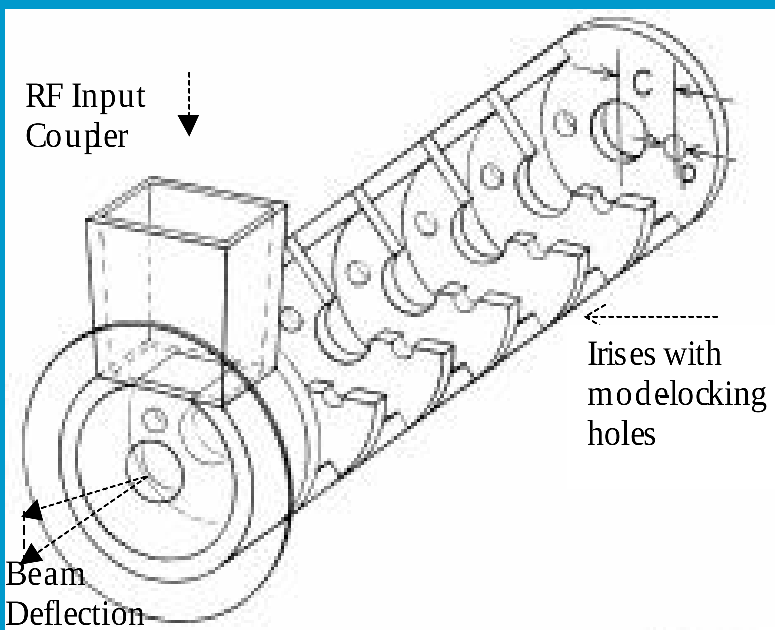
- accurate monitor critical for short wave FEL

Multi-stage compression

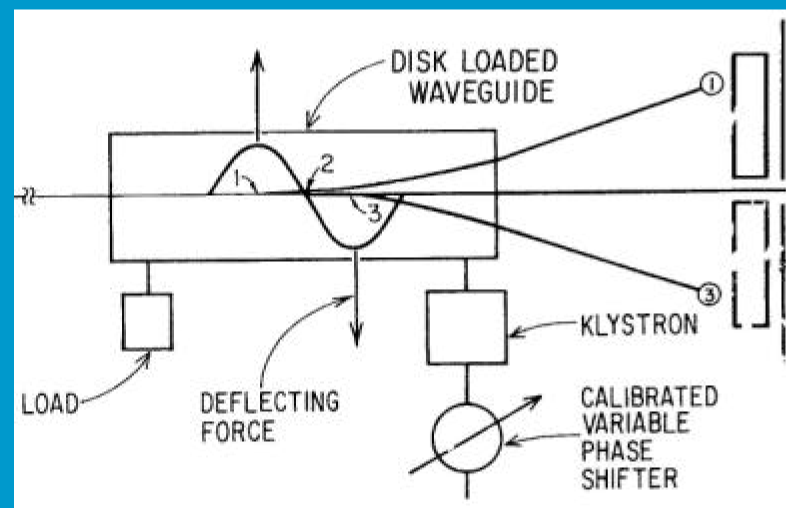


LCLS Bunch length monitor

- S-band deflecting TM11 structure



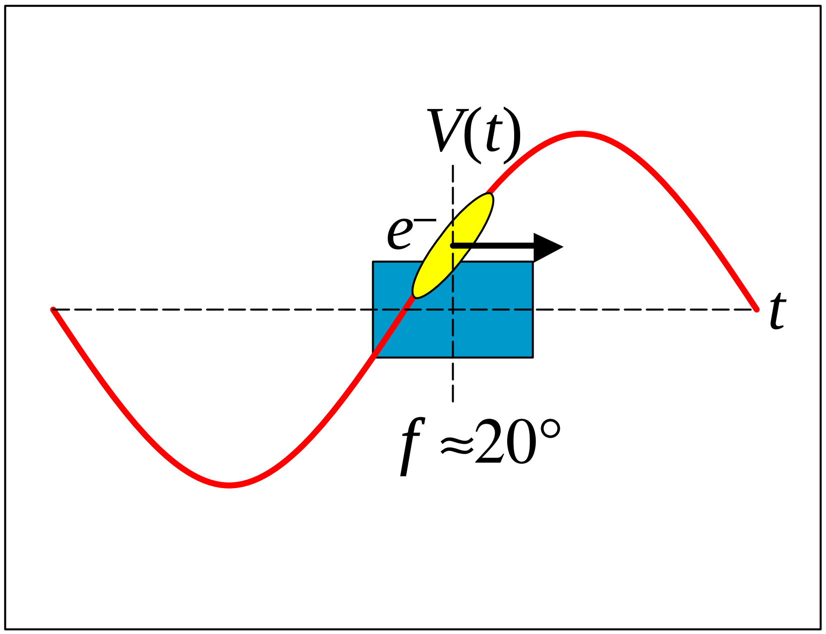
Schematic:

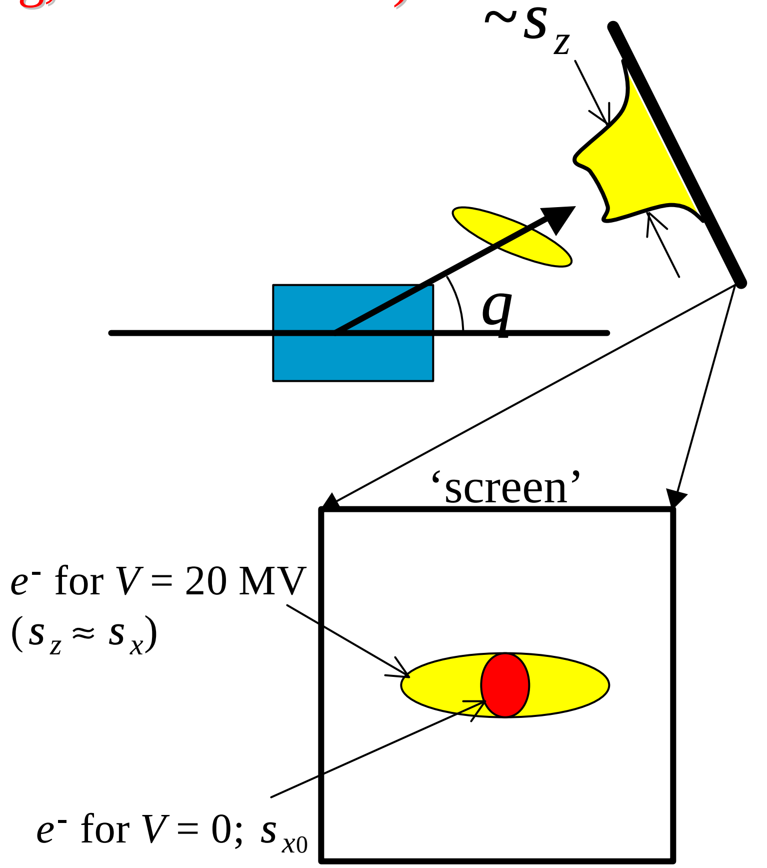


$$\sigma_z = \frac{\lambda_{rf}}{2\pi}\,\frac{\sqrt{E_d E_s}}{eV_0 \sin\Delta\psi \cos\varphi}\sqrt{\frac{\left(\sigma_y^2-\sigma_{y0}^2\right)}{\beta_d\beta_s}}$$

Bunch length monitor -

Transverse RF Cavity for Bunch Length and Slice-Emittance Measurements
(J. Frisch, X.-J. Wang, old SLAC '60s)





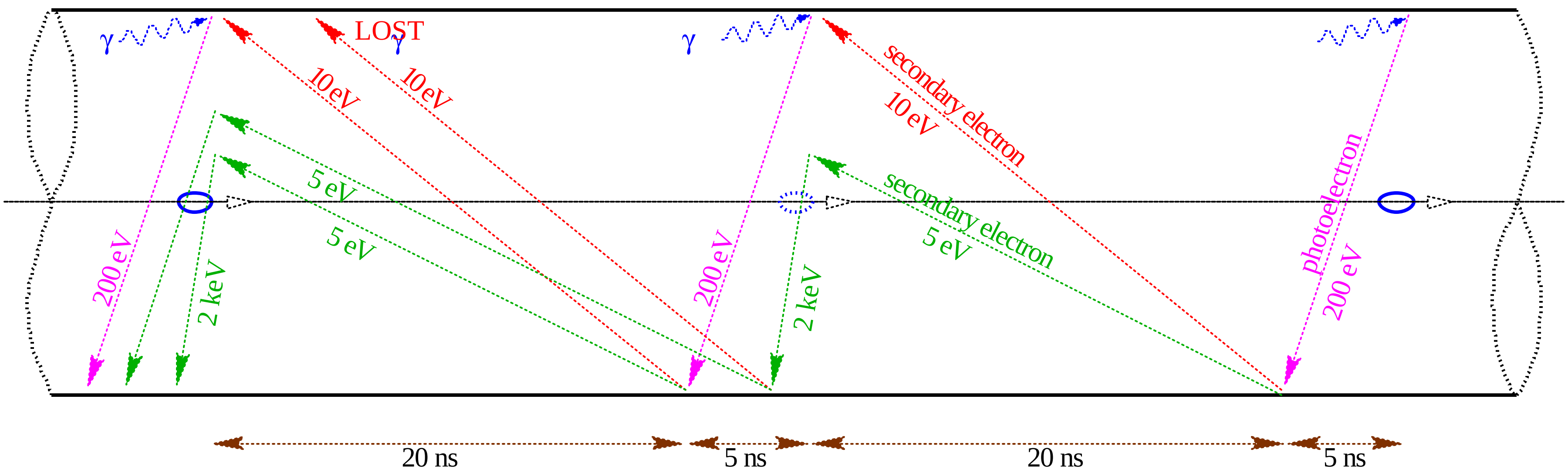
$$\sigma_z \approx \frac{\lambda E}{2\pi e V_0 \cos\varphi \sqrt{\beta_0 \beta_1} \sin\Delta\psi} \sqrt{\sigma_x^2 - \sigma_{x0}^2}$$

$V \approx 20$ MV at $\varphi \approx 20°$

Storage ring instabilities – electron cloud

A diffuse cloud of electrons gathers quickly and surrounds the positron (proton) beam.
Electrons generated by photoelectric/secondary emission

Very serious impact on b-factory / damping ring design and operation

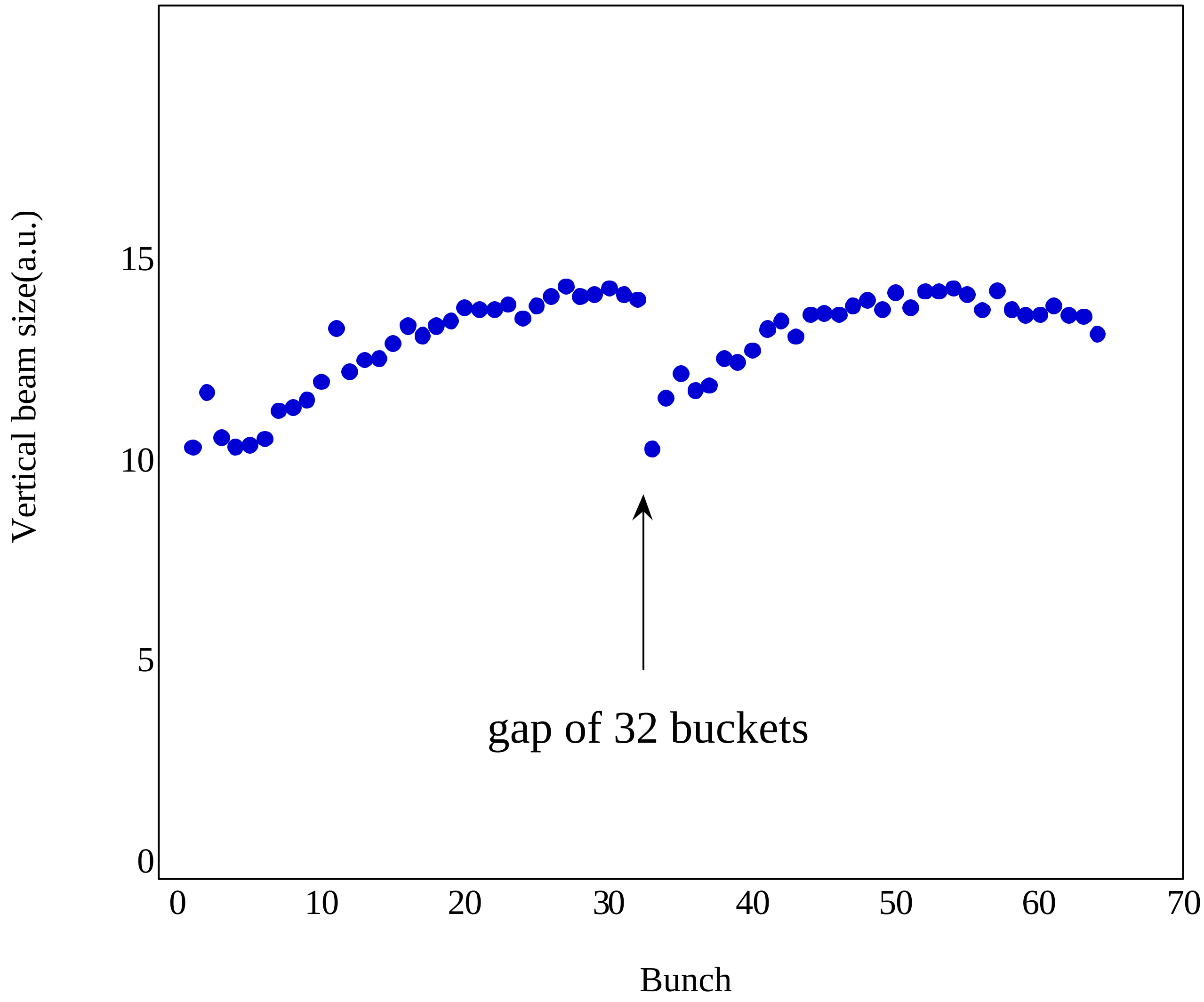


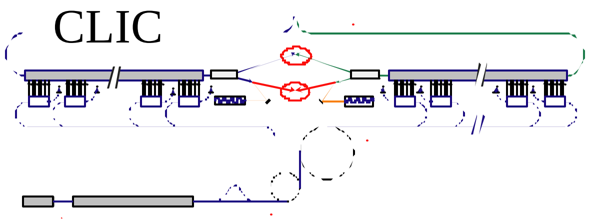
Schematic of electron-cloud build up in the LHC beam pipe.

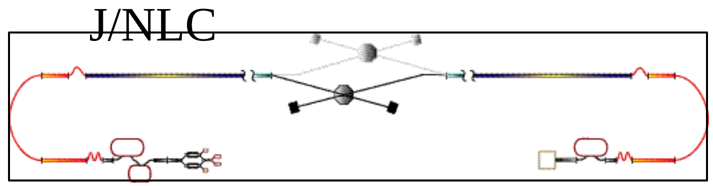
Electron cloud effect in KEK-B LER

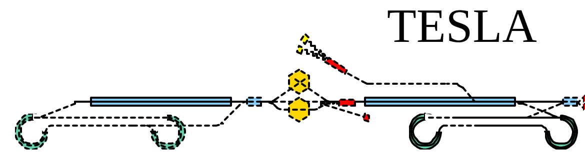
Showing the rise time of cloud density

Bunch spacing ~ 5 ns



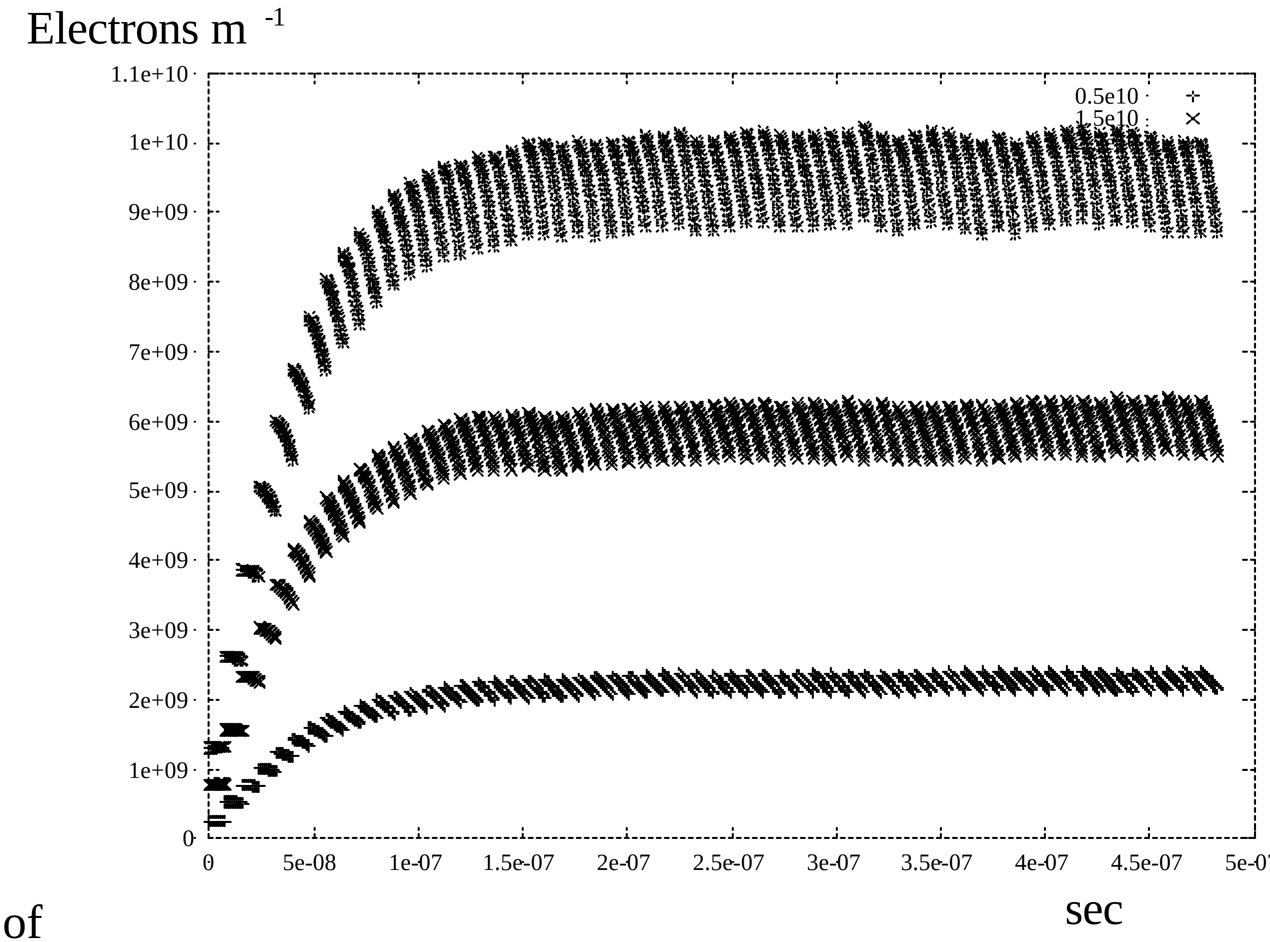




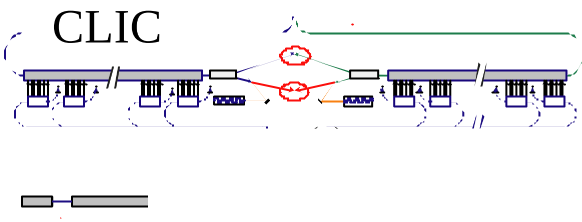


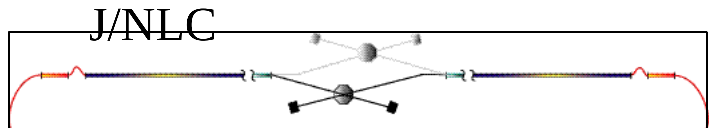
Buildup of electron cloud as a function of time

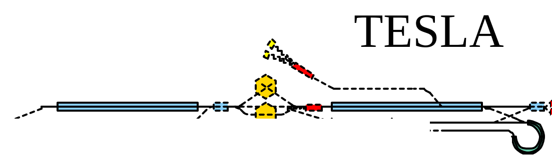
- during bunch train passage
- for 3 nominal bunch intensities
- (simulation)
- very little done for ‘direct’ measurements of cloud



Buildup of electron cloud (Simulation by F. Zimmermann)





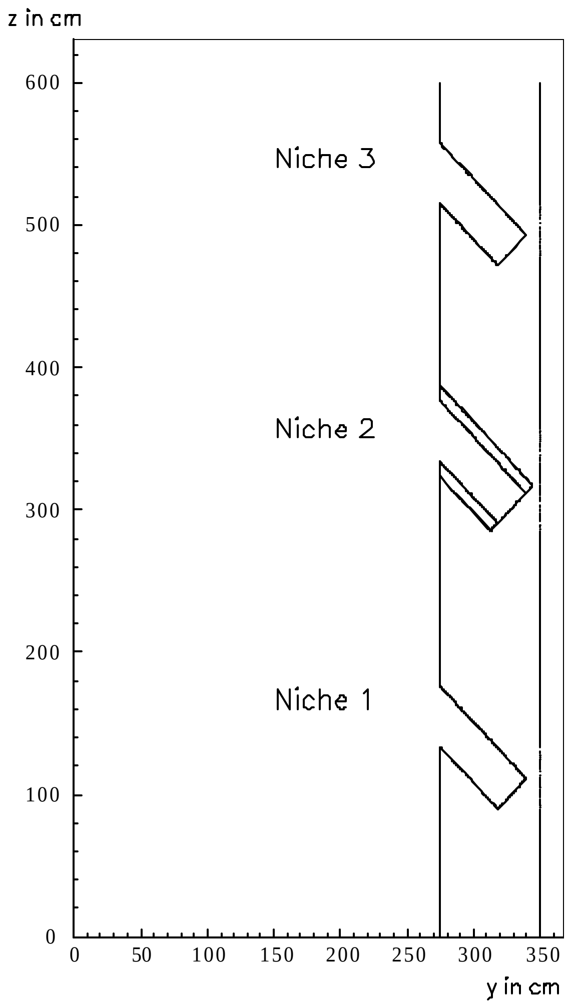


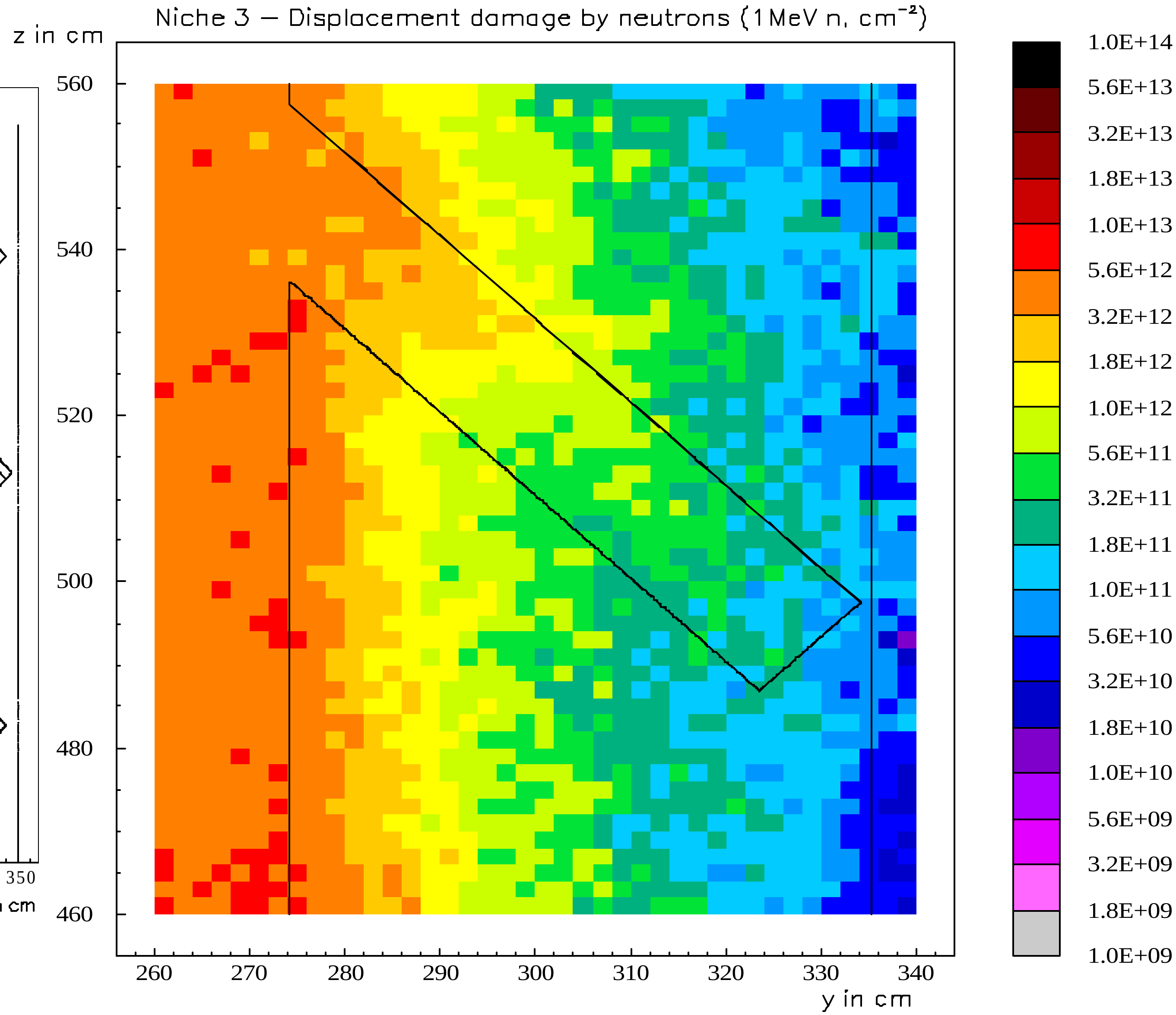
Radiation modeling

e-	$\uparrow$ prompt $\downarrow$ residual
p+	$\downarrow$ prompt $\uparrow$ residual

- Collider single beam power ~ 14 MW
  - (1 Rad/hr ~ 0.3 mW into 1 kg of material)

- Need to model:
  - locally installed electronics/plastics radiation dose
    - how much local shielding is needed?
    - Optics/Lasers/Electronics/HV power supplies/μwave components/?
  - material damage from extreme radiation
  - background processes for a variety of detectors
    - (not limited to IR)
  - machine component ‘damage’ processes
  - environmental – (NUMI)

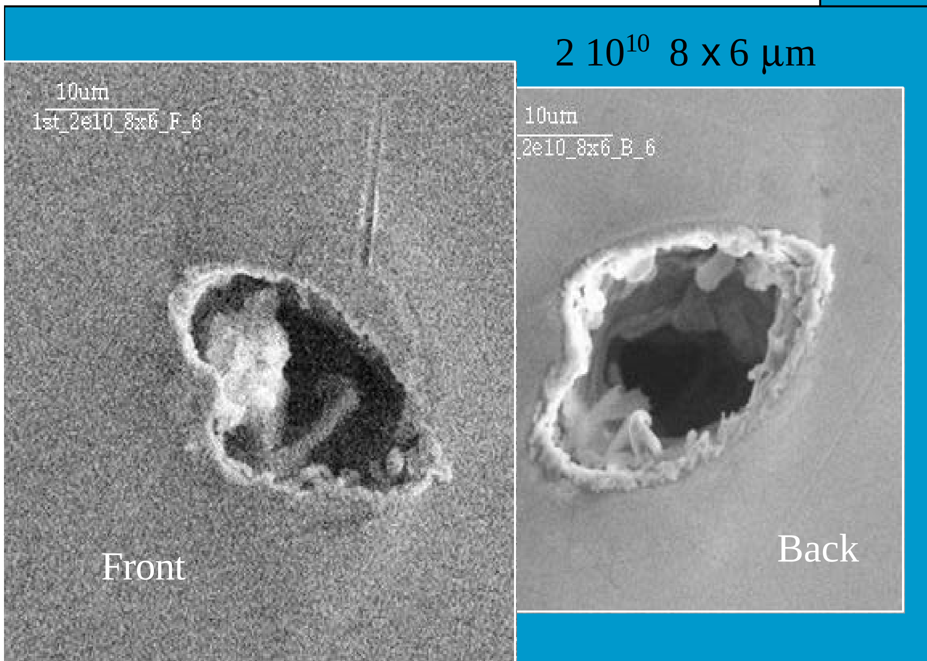


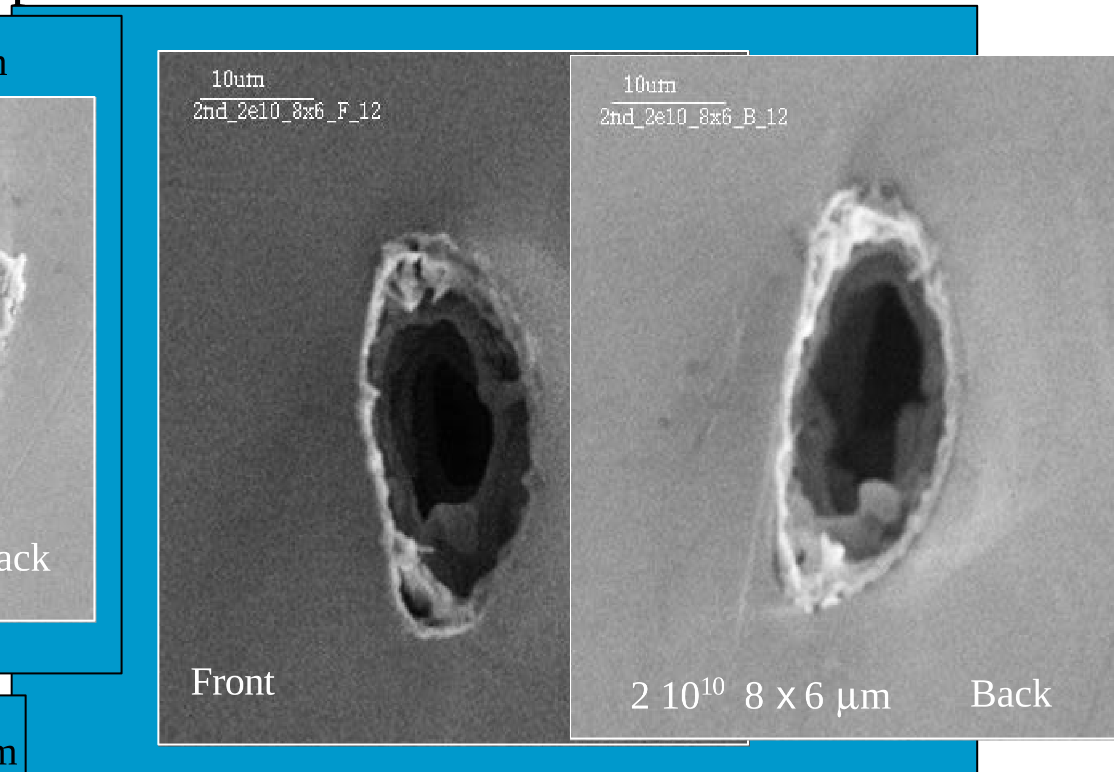


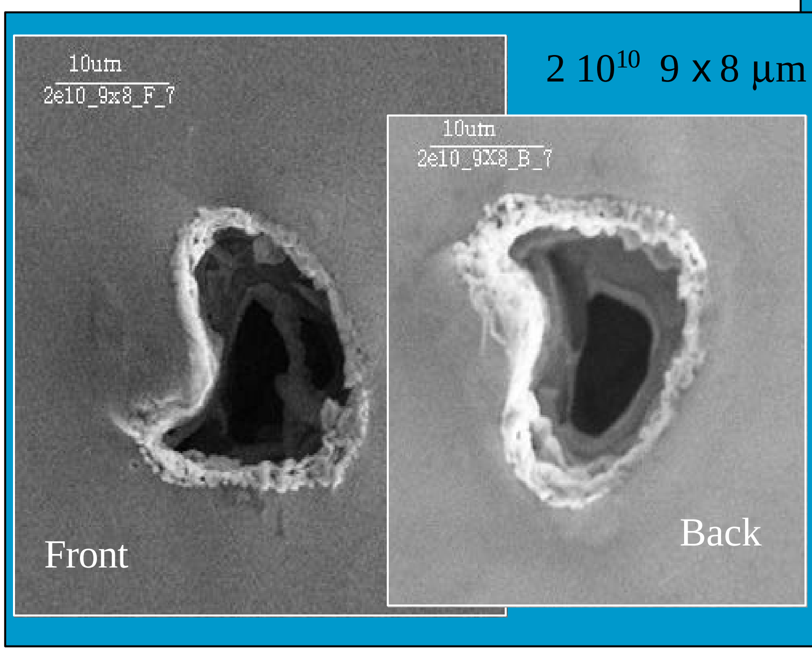
Tunnel electronics enclosures in main linac tunnel wall

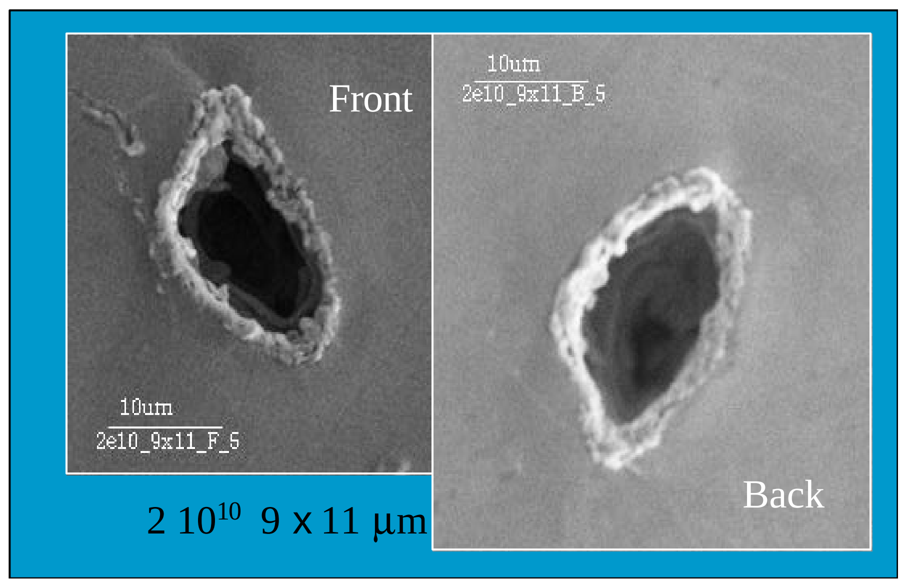
estimate of neutron fluence for 1.4W steady loss for 3000 days of operation

FFTB Single Pulse Damage Coupon Test - front and back side - same scale



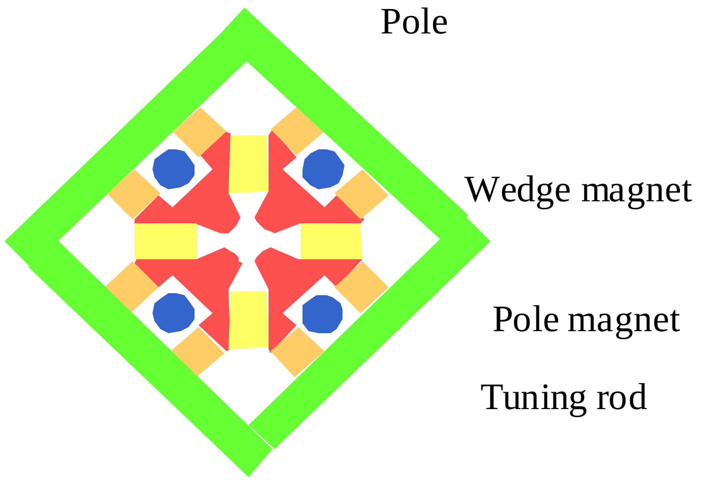


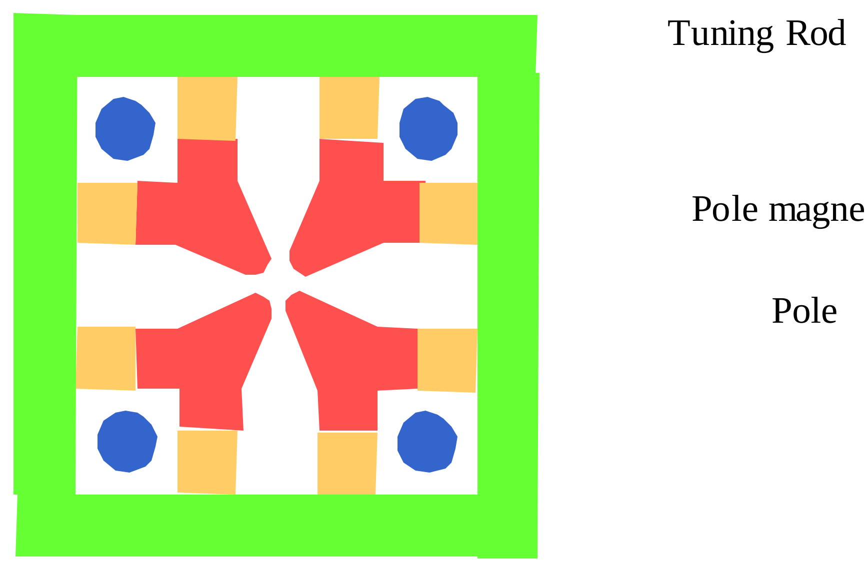




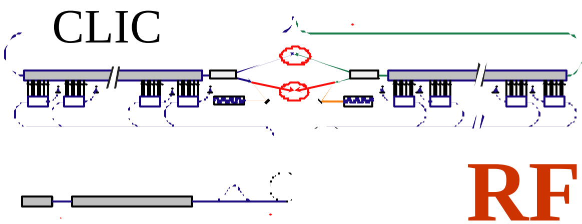
Permanent Magnets

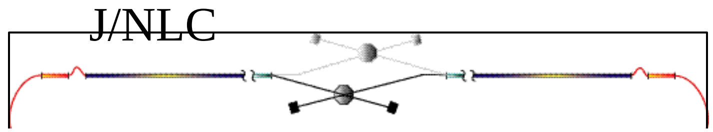
Corner Tuner

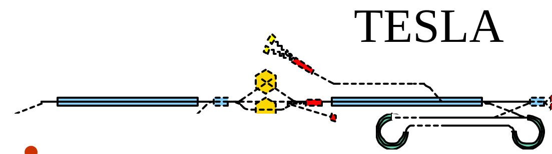




Wedge Magnet

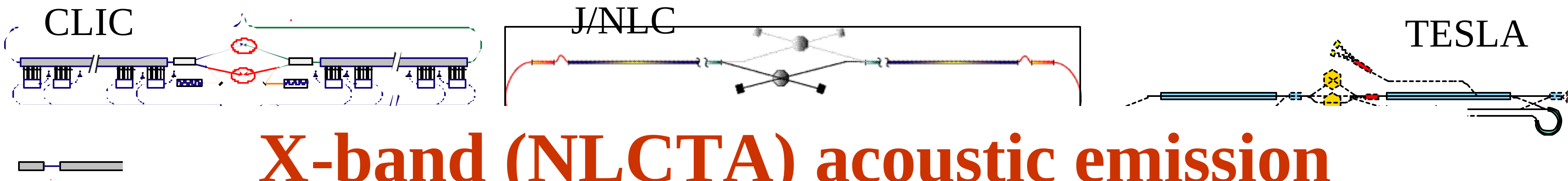






RF Breakdown Diagnostics

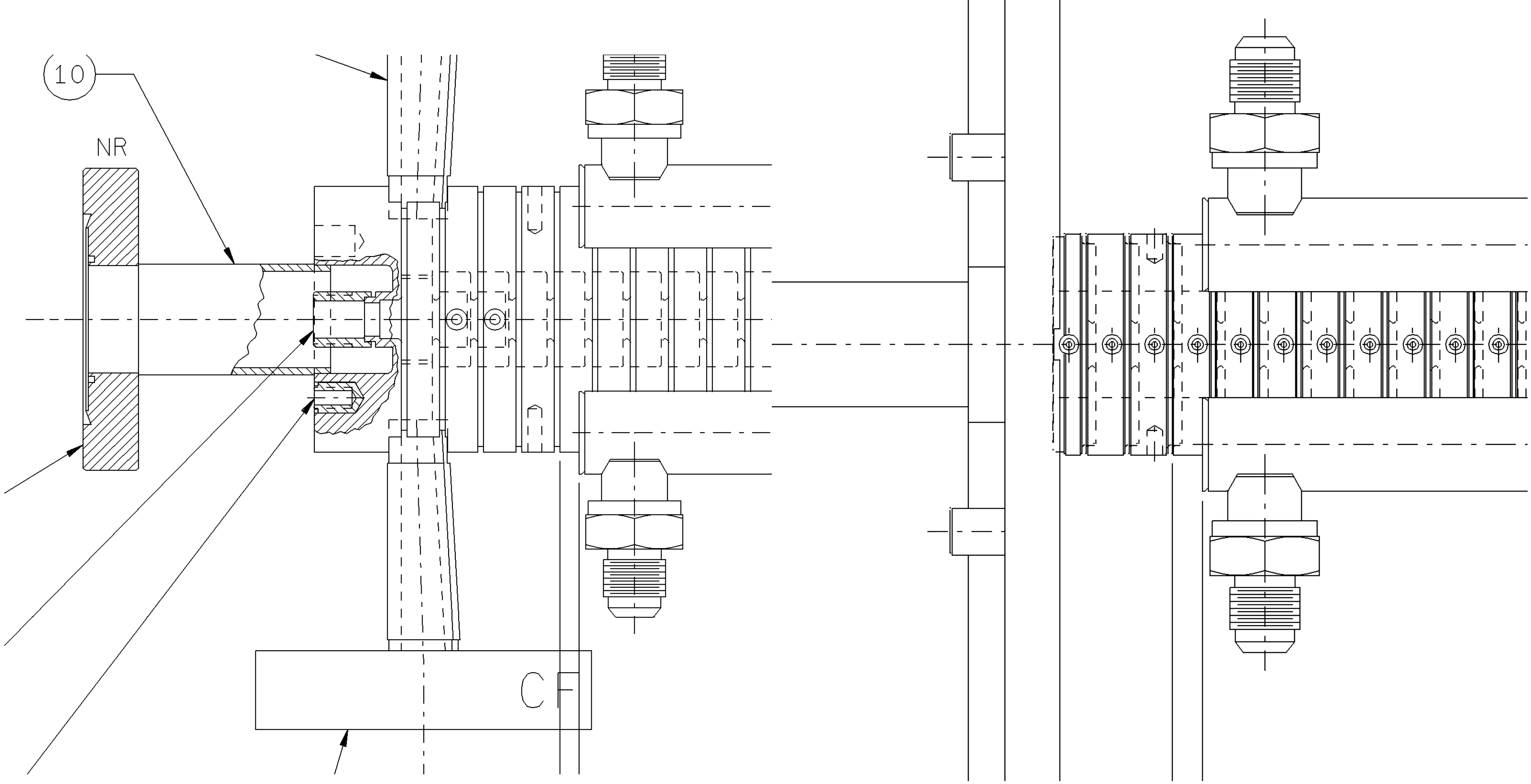
- Goals:
  - Location within mm
  - Quantify energy deposition
    - Comprehensive recording
  - Observe emitted light
- Provide feedback to manufacturing & fabrication process
- Optimize conditioning protocol
- Observations:
  - Multi-breakdown events caused by reflection
  - Breakdown grouping in time
  - Structure damage is not explained by material removed by arc pits themselves
  - Many (most) structures show enhanced concentration of breakdown in WG coupler



X-band (NLCTA) acoustic emission

- Clearly audible sound from breakdown – heard from n-1 generation transport components (e.g. flower petal mode converter, bends)
- Small, 1MHz bandwidth industrial or homemade sensors
- 10 MHz bandwidth recorders (3 samples/mm)
  - Look for start time (TTF) of 'ballistic phonons'
  - or Amplitude (NLCTA)
- Broadband mechanical impulse
  - (2001- limited by sensor performance)
  - Typ. $\lambda \sim 7$ mm

Acoustic sensor studies of input coupler breakdown

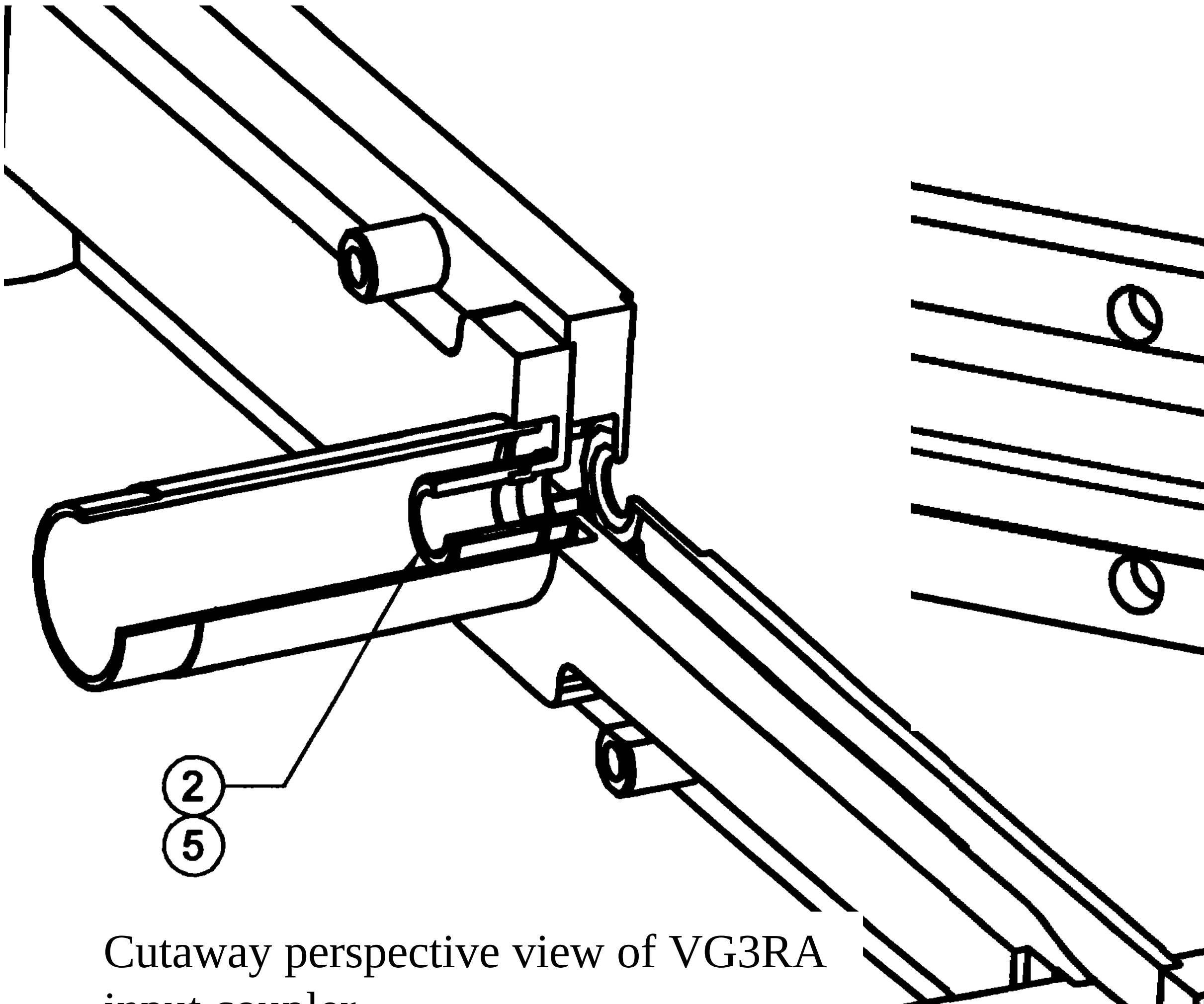


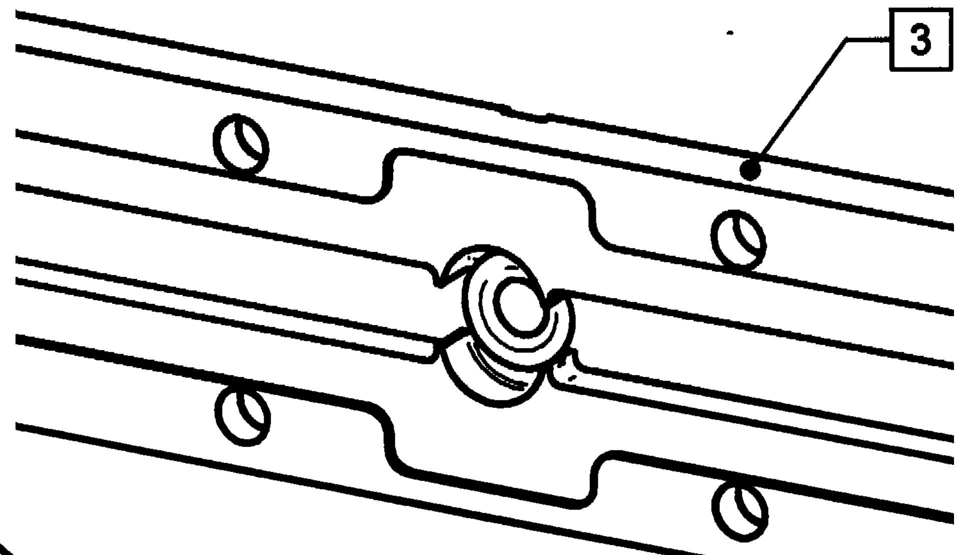
T53 VG3 F (KEK; diffusion bonded cell)

T53 VG3 RA (SLAC; H2 braze)

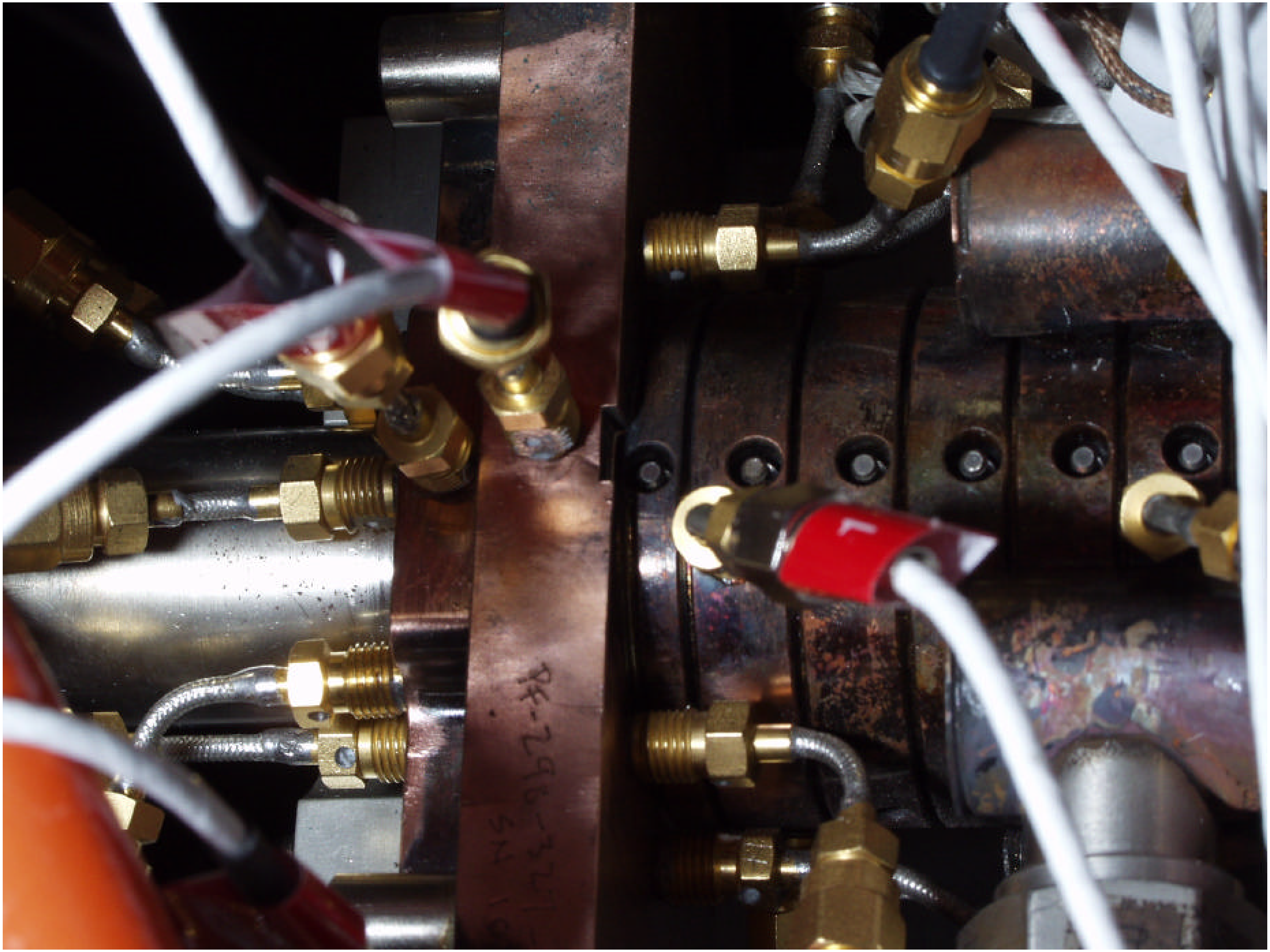
Plan views of two input coupler assemblies

Structure input coupler → exactly where are breakdown events?





Cutaway perspective view of VG3RA input coupler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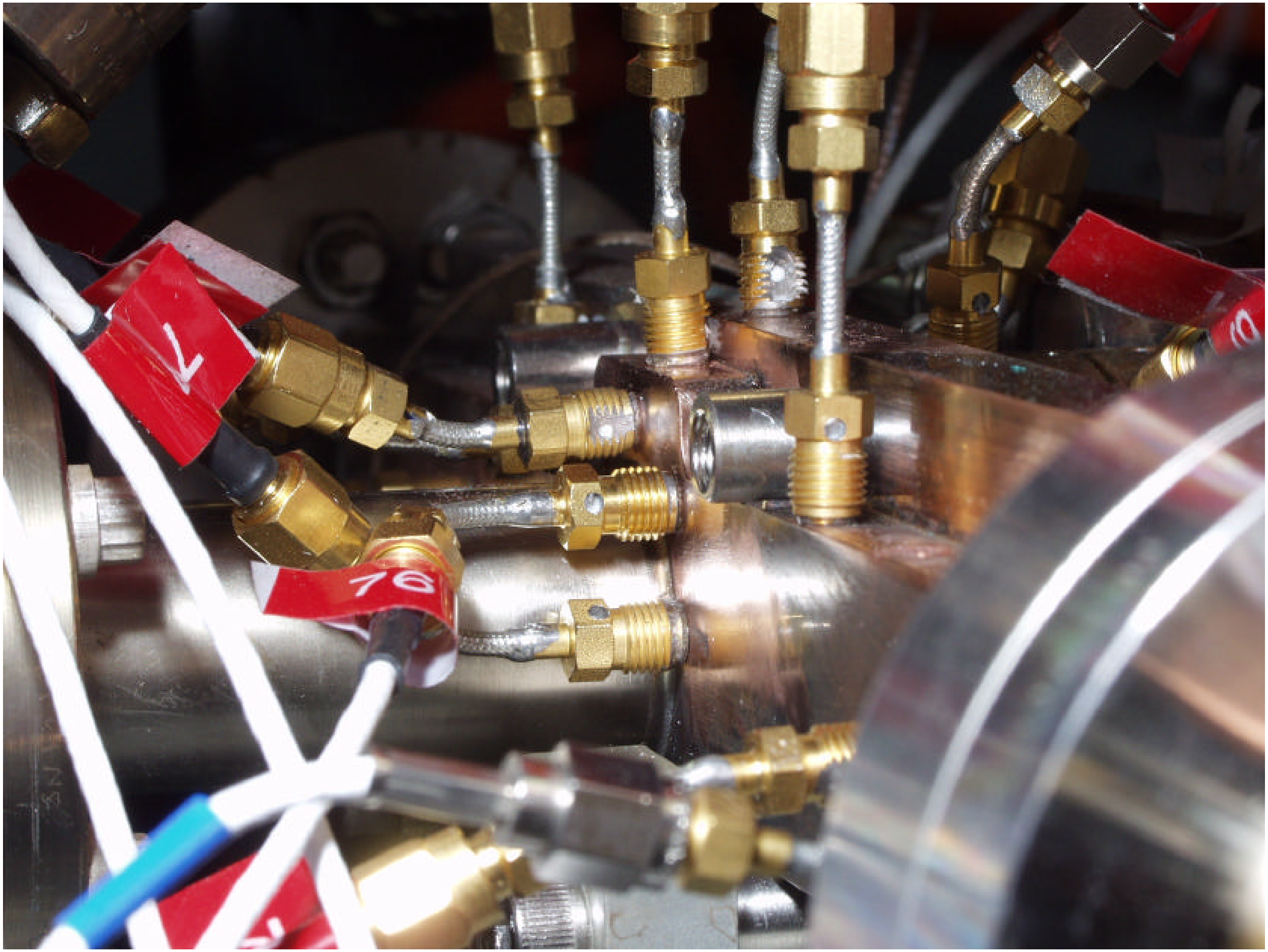
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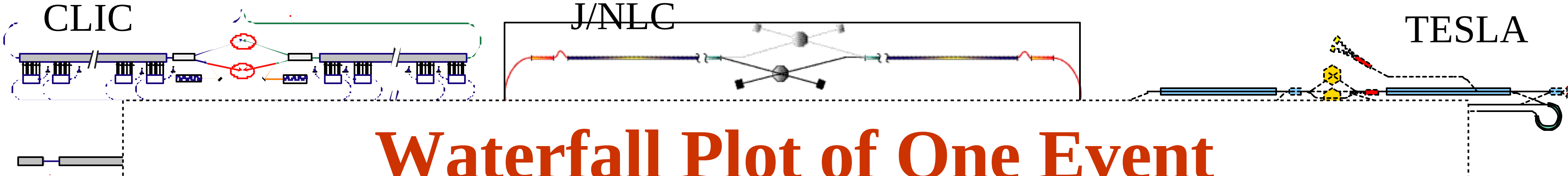
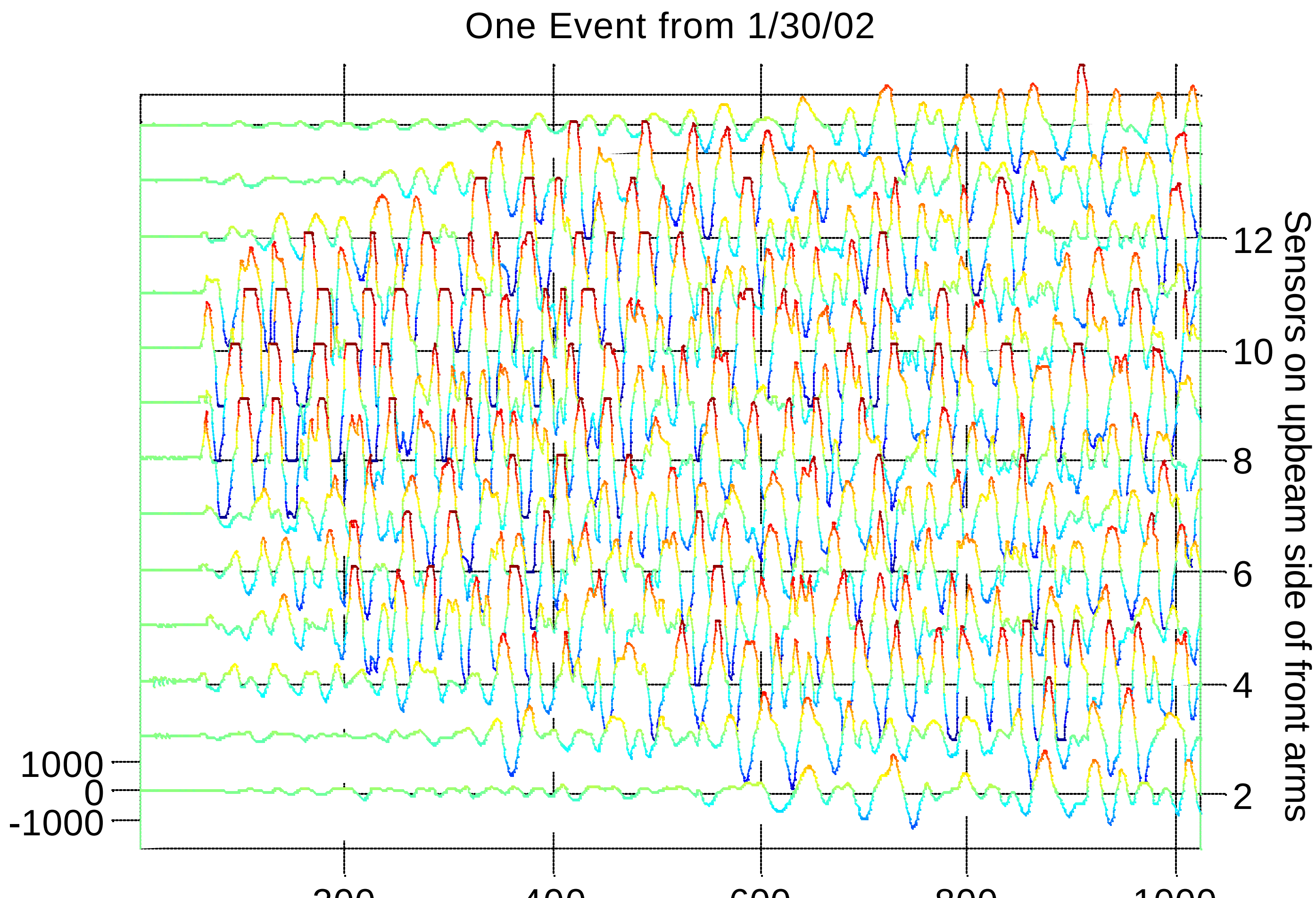
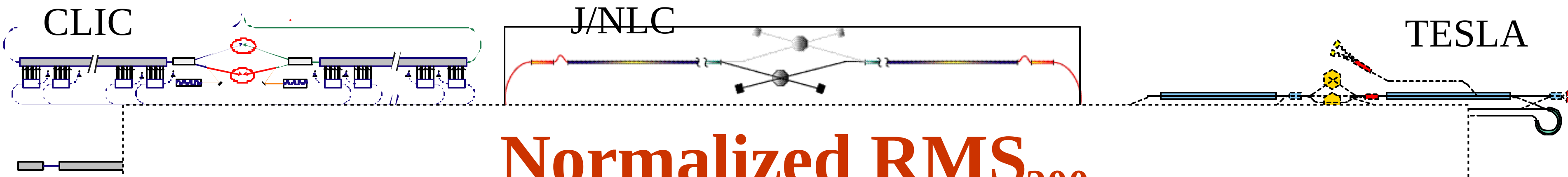


Waterfall Plot of One Event

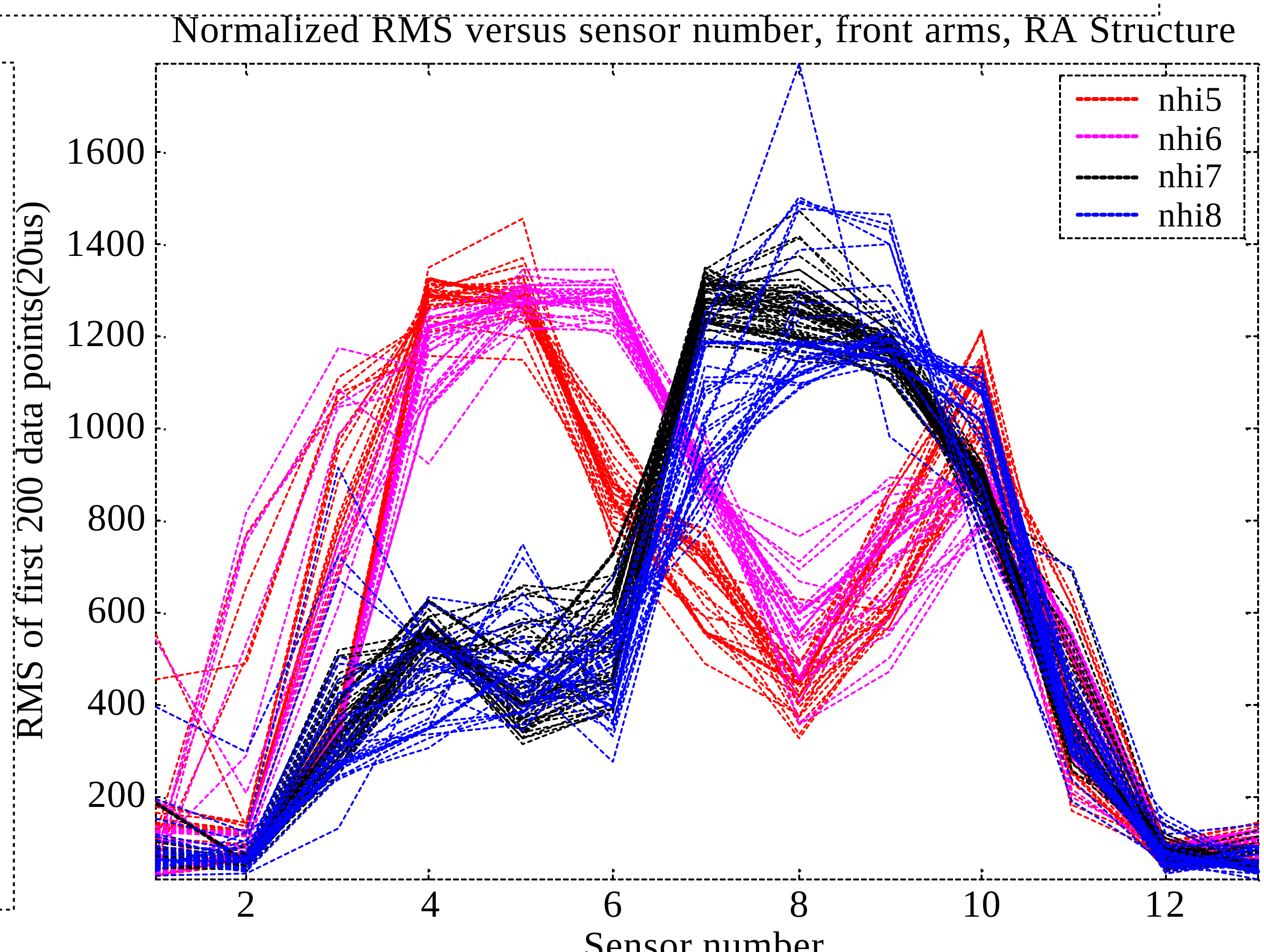
Shows saturation (seen after 1/29/02)



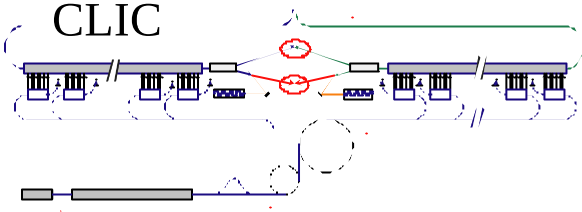


Normalized RMS_{200}

- Signals of a certain event-type are normalized such that all RMS_{1024} for a certain channel are equal.

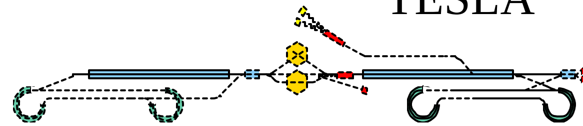


CLIC



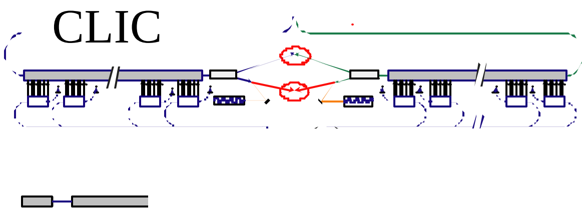
J/NLC

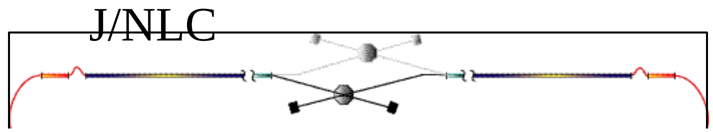
TESLA

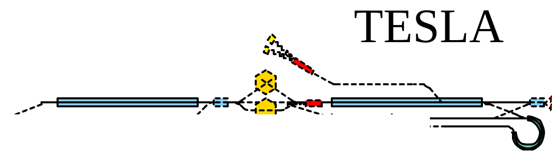


Control system

- Record (and keep) data from every pulse
  - (120 Hz NLC / 3MHz @ 0.5% duty cycle TESLA)
  - waveforms, feedback, feedforward
- Real – time pulse to pulse control
  - Guaranteed latency
  - ‘Machine Protection’
  - Feedforward from rings
- Feedback
  - Measure and correct
    - Sensors and correctors may be miles apart



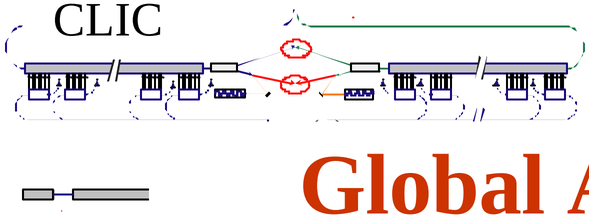


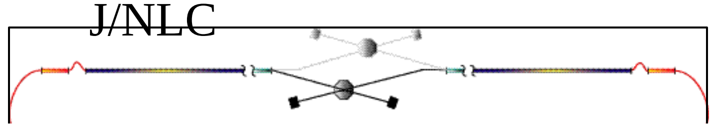


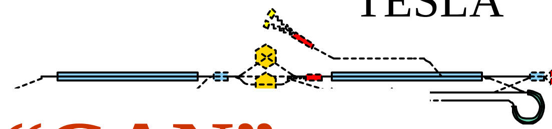
Machine Protection System (control system example)

- Single pulse response
  - Sensors on each ‘pulsed’ device
  - Prohibit extraction from the ring in case of anomaly
  - A huge set of dry contacts is not an appropriate solution

- Software
  - Need a fresh idea





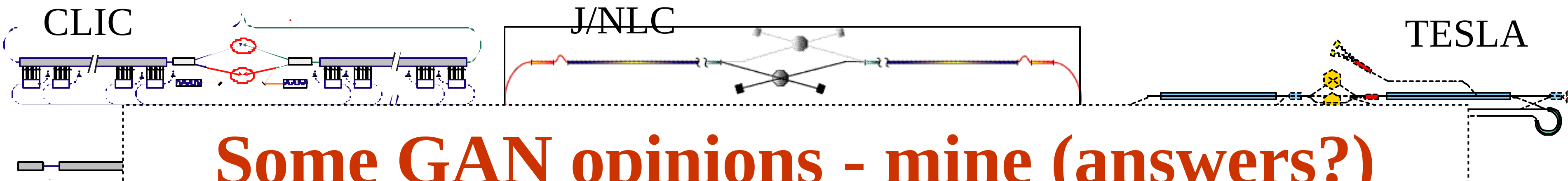


Global Accelerator Network "GAN"

- Proposal to ICFA from Wagner 3/00
  - Task force (Astbury/Willeke) report 12/01
- Primary purpose to develop global collaboration for LC construction and operation
  - (Snowmass 2001 evening plenary)

- Many questions: Will GAN provide →
  1. non-host labs with justification for personnel costs?
  2. non-host labs with venue for R D?
  3. host lab with staff?
  4. continuation of involvement following construction

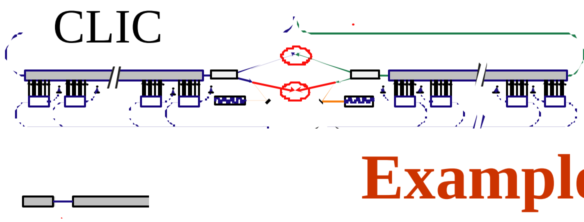
Who benefits from GAN?

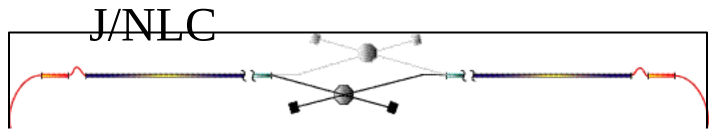


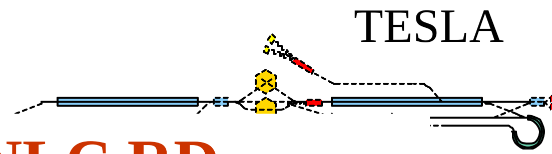
Some GAN opinions - mine (answers?)

- GAN DOES NOT PROVIDE JUSTIFICATION FOR NON-HOST LAB STAFFING
  - there must also be projects…
- The purpose of GAN is to maintain involvement/demand ongoing responsibility of those who built.
  - NOT like HERA, PEP2, SNS, LHC….
  - Construction proceeds through strong collaboration

- Why do you care?
  - How do you see the evolution of your involvement in the LC?







Example university involvement in NLC RD

- Feedback on nanosecond time scales (Oxford U – Burrows)
  - Two students posted at SLAC
  - Engineer and one student at Oxford
- Students operate NLCTA & are fully ‘trained’
- If a medieval institution like Oxford U can contribute to LC RD then so can you!

Concrete ideas about how to connect immediately (George)

Developed a kind of list – see Tom Himel

1. Precision microwave

   Electronics engineering
   Calibration, 'high performance' mixers
   Very similar to precision detector daq.

2. IR final doublet girder (~ internal to detector)

   Mechanical engineering
   Magnetics, acoustics
   ~ similar to VXD supports

3. Beam size from optical transition/diffraction radiation

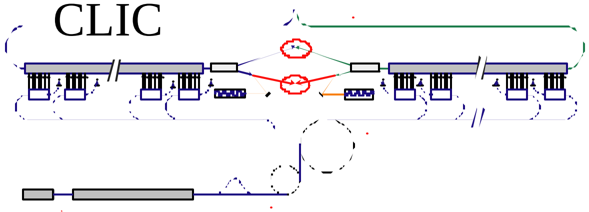
   Precision optics
   Electrodynamics of OTR
   VUV/Xray optics

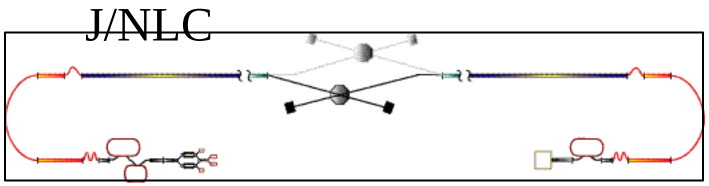
4. Bunch length

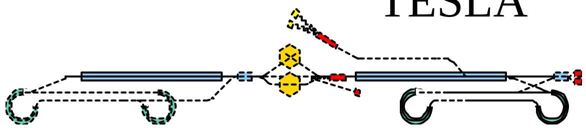
   FIR / mm wave optics,
   imaging and calorimetry
   Basic EM

5. Storage ring instabilities – electron cloud

   Materials science, surface
   science, electron
   detectors/energy analyzer







Modeling, including known radiation effects
Similar to LHC design work

6. Radiation modeling

Mechanical engineering
Field measurements, field stability

7. Permanent Magnets

8. RF breakdown

Instrumentation, microwave, acoustic, materials/surface science

9. Control system

Large scale software engineering, ~ similar to detector systems